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IMPACT OF RENEWABLE AND NON-RENEWABLE ENERGY TOWARD CO_2 EMISSIONS IN MALAYSIA

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ABSTRACT

In Malaysia, carbon dioxide (CO_2) emissions result from the usage of non-renewable energy sources. In recent decades, energy usage in Malaysia has significantly increased, driven by both residential and industrial factors. The increased demand for power is partially attributable to the nation's rapid economic development and urbanisation. Therefore, Malaysia is conscious of its responsibility in developing sustainable energy in order to fulfil SDG7 by 2030. This research analyses whether hydroelectric power, as a clean energy source, and various sources of fossil fuel-based energy affect CO_2 emissions in Malaysia. The research employs the Autoregressive Distributed Lag (ARDL) and Non-linear Autoregressive Distributed Lag (NARDL) methodologies to examine the cointegration between renewable and non-renewable energy for CO_2 emissions in the near term and extended term from 1970 to 2021. The findings showed that a near-term analysis reveals an inverted U-shaped Kuznets curve, where GDP positively impacts the release of CO_2 at 6,706 while GDP squared negatively affects it at -0.333. The ARDL extended-term analysis confirms this pattern, showing GDP as significantly positive at 7.505 and GDP squared as significantly negative at -0.394.

Introduction

Global warming is widely discussed phenomenon that represents a significant and enduring trend, posing one of the greatest challenges to the global environment due to its escalating impact. It is commonly perceived as a multifaceted problem, characterised by uncertainties and controversies. According to Al-Ghussain (2019), the phenomenon of climate change refers to higher Earth's average surface temperature due to an increased amount of greenhouse gases. Various factors contribute to global warming such as deforestation, fossil fuel usage (Raihan *et al*., 2021), urbanisation, industrialisation, and others. These factors may lead to an elevation in CO_2 levels, especially due to the influence of human activities on environmental pollution (Almulhim, 2021).

The research conducted by Ali *et al*. (2019) revealed that CO_2 emissions considerably impact the economic expansion of Pakistan. Furthermore, global warming is established to adversely impact economic expansion; yet, implementing actions to address climate change and adopt sustainable practices can also generate new economic opportunities. Therefore, in the long run, this includes opportunities for investing in clean energy sources, eco-friendly technologies, and resilient infrastructure to promote sustainable practice. A study by Raihan and Tuspekova (2022) highlighted that Malaysia has pledged a 45% reduction in the release of Greenhouse Gas (GHG) relative to national output by 2030, compared to year 2005.

The fast rise of world demand for energy has significantly affected the demographic and economic expansion of every country. These major environmental issues have been addressed by the United Nations Framework Convention on Climate Change (UNFCCC) and the starting of international climate change conferences including the 2015 Paris Climate Change Conference. Their focus had been on the worldwide climate change brought about by higher carbon dioxide (CO_2) emissions (Jardón *et al*., 2017).

Numerous cross-national studies examining the correlation among emissions, economic expansion, and clean energy frequently neglect regional disparities (Namahoro *et al*., 2021). Elauria (2017) asserted that ASEAN Centre for Energy (APAEC) and Asia-Pacific Economic Cooperation (APEC) have facilitated efforts to reinforce and augment the ASEAN region's obligations to pertinent multilateral environmental agreements. According to Forster *et al*. (2014) and Qin *et al*. (2019), factors that are relevant to inter-country environmental efforts on mitigating the economic impacts of pollution and growth consist of sustainable forest management, as well as responsible utilisation and management of marine ecosystems, natural resources, and freshwater supplies.

Numerous studies have investigated the correlation among economic conditions, GDP, and CO_2 emissions, alongside other macroeconomic variables; however, comprehensive empirical research on the pollution-economic expansion correlation yields variable findings (Apergis & Payne, 2015; Ahmad *et al*., 2017; Dogan & Ozturk, 2017). Ang (2007) and Mohamad *et al*. (2023)asserted that energy use directly influences carbon emissions. Understanding the linkages among these factors may provide significant indicators capable of resolving the conflicting impacts of economic, environmental, and energy conservation measures on each other (Soytas & Sari, 2009).

A multivariate panel analysis conducted by Apergis and Payne (2015) on nations categorised by the World Bank income classification revealed that the correlation between electricity usage and economic expansion is contingent upon a country's level of development. Conversely, Dagher and Yacoubian (2012) posited that the association between energy and national income has been defined for each country, thus, generalisations across nations at similar developmental stages or within the same geographical region are not feasible. The mutual correlation among the release of CO_2, energy usage, and national income significantly influences the selection of policies tailored to individual countries within distinct geographical and regional areas.

The world is becoming increasingly concerned with environmental conditions. However, reducing electricity usage is also seen as a challenging task, especially after many countries have undergone technological revolutions and now rely heavily on high levels of electricity. Many nations are beginning to recognise the significance of sustainable energy. Additionally, numerous countries have implemented green and environmentally friendly investment policies.

The comparison between investments in fossil fuel-based energy and eco-friendly energy, which refers to renewable energy is illustrated in Figure 1. The clean energy indicates an increasing trend in global investment, from more than 1,000 billion USD to more than 1,600 billion USD. On the other hand, fossil fuels exhibit a decreasing pattern in investment from 2015 to

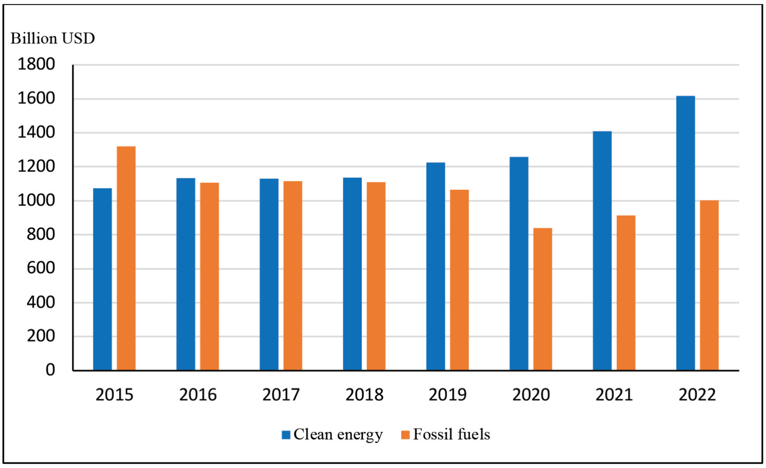

Figure 1: Global comparison of investment between clean and fossil fuel energy
Source: IEA

2020 and have shown a slow pace of increase since 2021. Nevertheless, the investment in clean energy has exceeded in fossil fuels from 2016 to 2022. This means there is a pervasive recognition and support for investments in sustainable resources and clean energy. Changes in investment patterns are critical to ensure our planet's extended-term viability and the well-being of future generations.

For far too long, the world has been overly reliant on fossil fuels, particularly during the era of heavy industrialisation in many developing countries. The entire globe eagerly embraced fossil fuels, including coal and petroleum, throughout the early modern industrial revolution. However, there is strong evidence that the suspension of fossil materials will harm the environment and will not last. One of the primary drivers of this shift in investment is the critical need to combat the environmental issues.

The release of greenhouse gases during the combustion of fossil fuels has long-term repercussion for the environment and contribute to global warming. Investing more in eco-friendly energy production can lessen our dependence on fossil fuels and help soften the blow of climate change. Moreover, if the world continues to rely on a fossil as energy source that will eventually run out, the world will face a critical energy crisis. As a result, efforts to achieve a more sustainable energy transition are significant and will benefit the world in the long run.

Therefore, this study is crucial in identifying the impacts of clean and fossil-based energy on the environment in Malaysia from 1970 to 2021. The study also examines the Kuznets curve to clarify the consequence of the Malaysian economy on carbon-intensive energy and clean energy usage.

Literature Review

Several studies (Cole, 2006; Shahbaz *et al*., 2014; Ren *et al*., 2014) have shown that different methods and tests used in these studies explain how energy usage can affect economic expansion.

Impact of Non-renewable and Renewable Energy

Despite broad agreement regarding the necessity of transitioning to clean energy, questions remain about how quickly and easily this can be accomplished. Based on the study of Vo *et al.* (2020), clean energy generated scalability towards the demand of energy usage and deployment costs, that possibly affects the level of reliability and energy security. Meanwhile, according to Ehigiamusoe and Babaola (2021), a high usage of electricity and openness to trade are two essential components that fuel economic expansion. Some studies argued that a rapid shift to renewables is necessary to mitigate climate change while others caution against overlooking the challenges associated with intermittency, energy storage, and infrastructure requirements (Liu *et al*., 2017).

Many nations around the world have given attention to energy needs and climate change because these issues are of great importance (IEA, 2013). The combustion of non-renewable resources will result in the release of large quantities of CO_2. The CO_2 emissions have experienced a 40% increase when compared to the early 1970s. The continued combustion of fossil fuels, which eventually causes global warming, is identified as the reason for this (Luqman *et al*., 2019; Mohamad & Ab-Rahim, 2024).

Although fossil fuels are gaining prominence in contemporary society due to accelerated population growth and evolving economic conditions, the detrimental impact of CO_2 has been demonstrated to significantly affect human life expectancy (Murthy *et al*., 2021; Huang *et al*., 2022). The finding was corroborated by Liang *et al*. (2022), which demonstrated a strong correlation among GDP, inflation in fossil fuel-based energy sources, and human capital.

The notion that CO_2 emissions from non-renewable energy sources may seriously affect the overall quality of life was also supported by the study performed by Sadekin (2021) and Hendrawaty *et al*. (2022). At the ASEAN region, the prevailing assessment is that the use of green energy, carbon-intensive energy, labour growth, and stock markets exhibit a positive correlation with the economic expansion of ASEAN nations.

According to the study by Fadilah *et al*. (2020), the association between carbon-intensive resources and GDP in the near term is positively cointegrated. Carbon-intensive energy sources continue to be the primary source of energy for the majority of Asian regions. Furthermore, they are still not fundamentally prepared for green energy and anticipate that the human capital index will suffer (Atiku *et al*., 2021; Huang *et al*., 2022).

Ehigiamusoe (2023) claimed that environmental deterioration has been partially attributed to using non-renewable energy for economic expansion. Correlations with clean energy, openness to commerce, and openness to foreign investment all have the potential to significantly alleviate the environment impact. Khan *et al*. (2022) obtained that the utilisation of clean energy adversely affects economic performance. Shakhabiddinovich *et al*. (2022) discovered that using more clean energy exerted a substantial and adverse influence on the valuation of green economy stocks.

However, other studies that were conducted arrived at different findings and discovered no negative effects on either the economy or the environment. When considering the environment, utilising clean resources as an electricity source will decrease the likelihood of El Nino phenomena (Albani *et al*., 2021).

A private company's creation of a clean power plant is anticipated to provide more economic expansion (Husaini & Lean, 2022). This is in addition to the fact that clean energy has the capability to significantly decrease hazardous gas release (Anwar *et al*., 2022). On top of that, there is also study that found positive cointegration between efficiency management in ASEAN countries and clean energy in the long run, using the Fully Modified Ordinary Least Square (FMOLS) and Dynamic Ordinary Least Squares Estimator (DOLS) analytical methods (Kumaran *et al*., 2020).

SDG Policy Debate

Current literature also reflects varying viewpoints on the most effective policy approaches to address economic expansion, sustainable energy, and carbon emissions (Charfeddine & Kahia, 2019). The role of market mechanisms, government intervention, and international cooperation were identified to be contentious and argued variably among recent studies

(Wang *et al*., 2013; Acheampong, 2018). Some argued in terms of market-based approaches such as carbon pricing to incentivise emission reductions while other studies advocated for more interventionist policies such as regulations and subsidies. Additionally, these arguments had contributed towards the contradicting predictors regarding the appropriate balance between global cooperation and national autonomy in addressing these complex challenges (Tong *et al*., 2020).

Some studies mentioned that economic expansion is a primary driver of greenhouse gas emissions and environmental deterioration, contributing to global warming (Ang, 2007; Alam *et al*., 2012). The authors emphasised the need to shift towards a carbon-efficient economy to mitigate climate change. On the other hand, some scholars (Antweiler *et al*., 2001; Arouri *et al*., 2012; Ahmed *et al*., 2017a) argued that economic expansion is essential for addressing poverty, improving living standards, and providing the resources and technology necessary for environmental deterioration mitigation.

Nonetheless, there is also an ongoing debate regarding the association between economic expansion and climate action, particularly in the context of Sustainable Development Goal (SDG) 7, laying emphasis on availability of cost-effective, dependable, eco-friendly, and advanced energy for all. Critics such as Alam *et al*. (2012) and Tong *et al*. (2020) disputed that pursuing economic expansion through carbon-intensive energy sources such as fossil fuels can undermine efforts to mitigate hazardous gas release and achieve the goals of SDG 7. Others proposed that transitioning to eco-friendly energy and pursuing extended-term development can be beneficial to the economy such as more employment and innovation (Apergis & Payne, 2015).

Measuring progress is also a pertinent issue relating to sustainable energy and economic expansion (Arouri *et al*., 2012). Apart from that, disagreements also arised regarding the measurement of progress in the context of global warming, SDG 7, and GDP. Some scholars argued that GDP, as a measure of economic activity fails to account for environmental costs and social well-being, leading to a narrow understanding of progress (Nasreen & Anwar, 2014; Lu, 2017). They advocated for alternative indicators such as genuine progress indicators that incorporate environmental and social factors. Additionally, there are arguments about the adequacy of existing metrics to measure progress in achieving SDG 7, particularly in capturing the multifaceted dimensions of energy access and sustainability (Gebara & Laurent, 2023).

Another area of scholarly contention pertains to energy access and climate justice. While SDG 7 seeks to ensure equitable availability of cost-effective, dependable, and advanced energy solutions, recent studies argued that current approaches might perpetuate inequalities, particularly for marginalised communities and developing countries (Lu, 2017). They emphasised the need for equitable and inclusive energy transitions, where access to clean energy and climate mitigation and adaptation technologies is prioritised for parties that are most vulnerable to climate change impacts (Sohag *et al*., 2015; Andreoni & Galmarini, 2016; Ahmad *et al*., 2017).

Environmental Kuznets Curve (EKC)

One major disagreement centres around the Environmental Kuznets Curve, which reflects an inverted U-shaped correlation between per capita income and environmental degradation (Menyah & Wolde-Rufael, 2010; Pao & Tsai, 2010; Nasreen & Anwar, 2014). Some studies argued that as economies grow wealthier, they become more environmentally conscious and invest in cleaner technologies, leading to a decline in carbon emissions (Payne, 2010; Ozturk, 2010). However, critics also argued that the EKC may not be universally applicable, that economic expansion can drive resource usage and emissions, undermining sustainability efforts (Bildirici & Kayikci, 2012).

Nonetheless, the issues of whether economic expansion can be effectively decoupled from carbon emissions are currently debated among researchers within the fields of economics and growth (Lu, 2017). Proponents argued that technological advancements and shifts towards cleaner energy sources can enable economic expansion without a corresponding increase in emissions (Nasreen & Anwar, 2014; Lu, 2017). However, sceptics argued that existing evidence of decoupling is limited and suggested that a more transformative shift in economic systems is required to achieve sustainable development (Salahuddin & Gow, 2014).

In line with the growing body of literature, there is also an ongoing debate regarding the potential trade-offs between economic expansion and sustainability goals. Many studies found comparative Kuznets on these issues. Critics of the studies of Arouri *et al*. (2012) and Salahuddin and Gow (2014) argued that a focus on economic expansion may prioritise short-term gains over extended-term sustainability, leading to environmental deterioration (Ahmed *et al*., 2017b). They emphasised the need to shift towards alternative indicators of progress beyond GDP to incorporate environmental and social dimensions while others contended that economic expansion could drive innovation and resource efficiency, ultimately leading to sustainability (Huang *et al*., 2008; Dogan & Ozturk, 2017; Jardón *et al*., 2017; Yaya, 2017).

The findings from the Granger causality test revealed that energy usage and carbon emissions have a bilateral correlation while other variables showed a one-way correlation leading to CO_2 emissions. Meanwhile, in the short term, there is no bilateral link between the converters, but there is a one-way link between open trade and FDI towards economic expansion, financial development, and CO_2 emissions (Ali *et al*., 2017; Butt *et al*., 2023).

However, the study by Ridzuan *et al*. (2020) revealed Kuznets curve was an inverted U shaped for the correlation between CO_2 emissions and economic development. The findings indicated that despite an increase in CO_2 emissions and extended-term economic development, there is eventually a decrease in CO_2 emissions when a certain level of growth was reached. The findings for Malaysia, in terms of the EKC hypothesis are consistent. In fact, a study conducted by Numan *et al*. (2022) demonstrated a negative correlation between the utilisation of clean energy and the ecological footprint.

Studies showed a significant impact between the use of clean energy, oil demand, and trade openness to CO_2 emissions, which also has a major impact on base makers in developing palm oil production as a solution to environmental deterioration (Suki *et al*., 2022; Khalid *et al*., 2023). ECC's growth strategy "grow now, clean then" has huge environmental costs and is unlikely to be able to be absorbed by the earth in the future (Rashid *et al*., 2018). Furthermore, the impact of trade and composition reduces CO_2 emissions, which improves environmental quality, whereas energy and comparative surpluses increase CO_2 emissions and degrade environmental quality (Sadat & Alom, 2016).

Technological innovation also aids in the reduction of carbon emissions and the environmental footprint. Kuznets' environmental coil hypothesis (ECC) was also confirmed for the country, demonstrating an inverted U-shaped correlation between economic expansion and environmental deterioration (Bekhet, 2020; Suki *et al*., 2022). Developed countries support the U-shaped Kuznets curve, which states that higher government spending initially increases inequality but eventually leads to positive effects after a certain threshold level is reached (Ram, 1988; Pirgaip *et al*., 2023). The growth of the urban population also does not affect CO_2 emissions in the short term.

However, energy usage and economic expansion can harm the environment in the near term (Shaari, 2021). There is also a focus on the six-dimensional impact of culture on ECC, which can be reduced due to two behaviours; masculinity and individualism, uncertainty, and extended-term orientation (Disli *et al*., 2016). In the long run, the response to carbon dioxide emissions can lead to negative impact towards the income for Malaysia (MLY), India (IND), Singapore (SNG), and the Philippines (PHL) (Wakimin *et al*., 2019).

Furthermore, future policies and global initiatives in sustainable development must integrate multidimensional cultural impacts on state behaviour on the environment and economic expansion, which are largely ignored in economic decision-making models (Disli *et al*., 2016). The findings of the Numan *et al*. (2022) study suggested that greener energy should be promoted in order to combat global warming. In fact, the government should encourage the development of low-carbon eco-tourism as well as the green development of both tourism and the economy (Sharif *et al*., 2020). Governments need to think about ways to reduce CO_2 emissions without sacrificing the country's economic expansion (Wahid *et al*., 2018). On a global scale, ASEAN governments should fund the development of energy infrastructure to increase renewable production capacity with zero emissions (Butt *et al*., 2023).

As a result of the studies conducted above, the foundation should encourage local and foreign investors to invest more in clean energy usage, technological innovation in the Malaysian economy, and the use of green technology in domestic business (Bekhet, 2020; Suki *et al*., 2022). In addition, developing countries must follow a different path of growth than the ECC. Naturally, most industrial factories significantly contribute to pollution and governments should frame a special foundation for clean energy by imposing taxes on fossil fuels and subsidising companies that enhance the use of clean energy (Sadat & Alom, 2016; Rashid *et al*., 2018; Wakimin *et al*., 2019). The results of the studies by Sadat and Alom (2016) and Bekhet (2020) also suggested that increased energy efficiency, implementation of energy-saving projects, and external sources of energy infrastructure can reduce the level of pollution generated by urban areas.

As a concluding remark, differences exist in the literature regarding the policy priorities and pathways for addressing global warming, SDG 7, and GDP in the global context. Disagreements arise over the emphasis on mitigation versus adaptation strategies, the role of international cooperation, and the appropriate balance between market mechanisms and government interventions. Some argued for a rapid transition to clean energy and ambitious climate targets while others highlighted the importance of flexibility and contextualised approaches to accommodate diverse national circumstances and development needs.

Methodology

The data were collected from trusted international sources worldwide, including World Bank Indicator, Our World in Data (OWiD), and BP World Energy. The measurement of CO_2 emissions in million metric tonnes per capita (MMT) is an important element for assessing the level of environmental deterioration and promoting sustainability. This study proxies the economic situation by using gross domestic product (GDP), which is appropriate for evaluating Kuznets theory. Additionally, the use of GDP squared provides the next stage in unravelling the existence of the inverted U-shape.

Foreign Direct Investment is an important variable that enables the non-linearity ARDL method. The inflows of this variable towards the economy have both positive and negative effects. The usage of hydro energy, which is a clean energy source is considered the most sustainable option. It has sufficient data available for up to 52 years, in comparison to other renewable energy sources like solar, wind, and waves. The non-renewable energy studied is based on coal, oil, and gas, all of which are derived from fossils. All of these data are logarithmically transformed to achieve a higher resolution in data analysis.

The following is a model for the study variables:

$$LCO_2 = f(LGDP_t, LGDP2_t, LFDI_t, LHYDRO_t, LCOAL_t, LOIL_t, LGAS_t) \quad \text{(i)}$$

Equation (i) may be rewritten as follows:

$$LCO_2 = \alpha_0 + \alpha_1 LGDP_t + \alpha_2\, LGDP2_t + \alpha_3\, LFDI_t + \alpha_4\, LHYDRO_t + \alpha_5\, LCOAL_t + \alpha_6\, LOIL_t + \alpha_7\, LGAS_t + \varepsilon_t \qquad \text{(ii)}$$

The model coefficients are $\alpha_1 - \alpha_6$, ε_t as the error term in the model and t identify as the time series data (1970-2021), Equation iii represents the ARDL model derived from the framework established in Equation ii. According to Pesaran *et al*. (2001), the ARDL approach is considered a robust and dependable technique that may be utilised to acquire a better understanding of the short-term and extended-term correlations that exist between the variables. Additionally, the F-test is required as the bound test in order to guarantee that there is extended term cointegration. Root testing is an important step that must be completed before enabling this approach.

In the Malaysian region, the Kuznets curve analysis has been the subject of numerous studies. Carbon dioxide emissions, energy usage, gross domestic product, financial development, and urbanisation in Malaysia from 1970 to 2013 were the factors examined by Bekhet *et al*. (2020). In other study, variables such as the gas, oil, coal, and electrical power usage, as well as CO_2 emissions and real income per capita are used by Saboori and Sulaiman (2013) to analyse the Kuznets curve in Malaysia. Some research related to the Kuznets curves within the Malaysia region include agriculture, GDP, CO_2, and renewable energy in their models from 1987 to 2016 (Rizuan *et al*., 2020). Then, study by Go *et al*. (2021) presented the Kuznets curve in Malaysia from the point of view of transportation from the year 1990 all the way up until 2017.

Kuznets curve analysed by Suki *et al*. (2020) used the ecological footprint, GDP, and globalisation to clarify the Quantile Autoregressive Distributed Lag (QARDL) of Malaysia from 1970 until 2018. Almost similar research conducted about the QARDL in Malaysia from 1995Q1 until 2018Q4, with adding the element of tourism and transportation in the model (Sharif *et al*., 2020). In the research by Ali *et al*. (2020), they investigated the Kuznets curve by examining technology aspect (technical innovation), structural changes, CO_2 emissions, energy usage, and economic expansion in Malaysia from 1985 to 2016. Ridzuan *et al*. (2022) employed a study model incorporating CO_2 emissions, GDP, domestic investment, foreign investment, energy usage, trade openness, and infrastructure in Malaysia from 1971 to 2019.

The study of Malaysia Kuznets curve that included the element of COVID-19, financial development, and income inequality was conducted by Ridzuan (2021), which compared other Southeast Asian countries such as Indonesia, Thailand, and Philippine from 1970 until 2016. Other than that, a study that covered the year 1980-2017 examined energy efficiency in Malaysia by looking at economic efficiency, labour, financial (capital), energy productivity, trade openness, and inflation (Karim *et al*., 2022). In another example, a study conducted by Ong *et al*. (2021) using GDP, population, financial development, and the Environmental Performance Index (EPI) from 2002 to 2017 examined the correlation between economic expansion and environmental impacts in Malaysia. Aslam *et al*. (2021) employed a Kuznets curve framework to examine industries influencing CO_2 emission globally in Malaysia.

However, there are still lack of study conducted to examinate the EKC curve in Malaysia in the form of an inverted U-shape over a 52-year period from 1970 to 2021. To fulfil the gap, the current study uses economic conditions, hydro energy, and non-renewable energies to analyse the environmental condition in Malaysia in the context of the Kuznets curve. This study selects CO_2 emissions, economic factors (comprising GDP and its square), and both renewable and non-renewable energy sources as variables. In the framework as shown in Table 3, there are the variable names, along with their corresponding measurement units and descriptions.

$$\Delta LCO2_t = a_1 + \sum_{i=1}^{a} \alpha_{1i} \Delta LCO2_{t-i} + \sum_{i=0}^{b} \alpha_{2i} \Delta LGDP_{t-i} + \sum_{i=0}^{c} \alpha_{3i} \Delta\, LGDP2_{t-i} + \sum_{i=0}^{d} \alpha_{4i} \Delta LFDI_{t-i} + \sum_{i=0}^{e} \alpha_{5i} \Delta LHYDRO_{t-i} + \sum_{i=0}^{f} \alpha_{6i} \Delta LCOAL_{t-i} + \sum_{i=0}^{g} \alpha_{7i} \Delta LIOL_{t-i} + \sum_{i=0}^{h} \alpha_{8i} \Delta LGAS_{t-i} + \beta_1 LGDP_{t-1} + \beta_2 LGDP2_{t-1} + \beta_3 LFDI_{t-1} + \beta_4 LHYDRO_{t-i} + \beta_5 LCOAL_{t-i} + \beta_6 LOIL_{t-i} + \beta_7 LGAS + \varepsilon_t \quad \text{(iii)}$$

The nonlinear ARDL has the concept of "hidden cointegration", wherein cointegrating correlations between the positive and negative components are more focus to be explored (Shin *et al*., 2014). This study only focusses on the energy usage and taken place to be explored for the hidden cointegration. Thus, equations iv - xi demonstrate the renewable and non-renewable energies (hydro, coal, oil, and gas) with positive and negative shocks (LHYDRO±; LCOAL±; LOIL±; LGAS±) being taken into consideration. The variables are as shown in Table 1:

$$LHYDRO^{+} = \sum_{i=1}^{t} \Delta\, LHYDRO^{+}{}_{i} = \sum_{i=1}^{t} max\ (\Delta LHYDRO^{+}{}_{i}, 0) \quad \text{(iv)}$$

$$LHYDRO^{-} = \sum_{i=1}^{t} \Delta\, LHYDRO^{-}{}_{i} = \sum_{i=1}^{t} min\ (\Delta LHYDRO^{-}{}_{i}, 0) \quad \text{(v)}$$

$$LCOAL^{+} = \sum_{i=1}^{t} \Delta\, LCOAL^{+}{}_{i} = \sum_{i=1}^{t} max\ (\Delta LCOAL^{+}{}_{i}, 0) \quad \text{(vi)}$$

$$LCOAL^{-} = \sum_{i=1}^{t} \Delta\, LCOAL^{-}{}_{i} = \sum_{i=1}^{t} min\ (\Delta LCOAL^{-}{}_{i}, 0) \quad \text{(vii)}$$

$$LOIL^{+} = \sum_{i=1}^{t} \Delta\, LOIL^{+}{}_{i} = \sum_{i=1}^{t} max\ (\Delta LOIL^{+}{}_{i}, 0) \quad \text{(viii)}$$

$$LOIL^{-} = \sum_{i=1}^{t} \Delta\, LOIL^{-}{}_{i} = \sum_{i=1}^{t} min\ (\Delta LOIL^{-}{}_{i}, 0) \quad \text{(iv)}$$

$$LGAS^{+} = \sum_{i=1}^{t} \Delta\, LGAS^{+}{}_{i} = \sum_{i=1}^{t} max\ (\Delta LGAS^{+}{}_{i}, 0) \quad \text{(x)}$$

$$LGAS^{-} = \sum_{i=1}^{t} \Delta\, LGAS^{-}{}_{i} = \sum_{i=1}^{t} min\ (\Delta LGAS^{-}{}_{i}, 0) \quad \text{(xi)}$$

$$\Delta LCO2_t = a_1 + \sum_{i=1}^{a} \alpha_{1i}\Delta LCO2_{t-i} + \sum_{i=0}^{b} \alpha_{2i}\Delta LGDP_{t-i} + \sum_{i=0}^{c} \alpha_{3i}\Delta LGDP2_{t-i} + \sum_{i=0}^{d} \alpha_{4i}\Delta LFDI_{t-i} + \sum_{i=0}^{e} \alpha_{5i}\Delta LHYDRO^{+}{}_{t-i} + \sum_{i=0}^{f} \alpha_{6i}\Delta LHYDRO^{-}{}_{t-i} + \sum_{i=0}^{g} \alpha_{7i}\Delta LCOAL^{+}{}_{t-i} + \sum_{i=0}^{h} \alpha_{8i}\Delta LCOAL^{-}{}_{t-i} + \sum_{i=0}^{i} \alpha_{9i}\Delta LOIL^{+}{}_{t-i} + \sum_{i=0}^{j} \alpha_{10i}\Delta LOIL^{-}{}_{t-i} + \sum_{i=0}^{k} \alpha_{11i}\Delta LGAS^{+}{}_{t-i} + \sum_{i=0}^{l} \alpha_{12i}\Delta LGAS^{-}{}_{t-i} + \beta_1 LGDP_{t-1} + \beta_2 LGDP2_{t-1} + \beta_3 LFDI_{t-1} + \beta_4 LHYDRO^{+}{}_{t-1} + \beta_5 LHYDRO^{-}{}_{t-1} + \beta_6 LCOAL^{+}{}_{t-1} + \beta_7 LCOAL^{-}{}_{t-1} + \beta_8 LOIL^{+}{}_{t-1} + \beta_9 LOIL^{-}{}_{t-1} + \beta_{10} LGAS^{+}{}_{t-1} + \beta_{11} LGAS^{-}{}_{t-1} + \varepsilon_t \quad \text{(xii)}$$

Table 1: Variables table

Variable Clarification	Variable	Source	Unit
CO_2 emissions per capita	LCO_2	Our World in Data	Metric tons per capita
Gross domestic product	LGDP	World Bank Indicator	Constant 2015 US$
Gross domestic product	LGDP2	World Bank Indicator	Constant 2015 US$
Foreign direct investment	FDI	World Bank Indicator	US$
Hydro energy usage	LHYDRO	BP World Energy	Exajoules
Coal energy usage	LCOAL	BP World Energy	Exajoules
Oil energy usage	LOIL	BP World Energy	Exajoules
Gas energy usage	LGAS	BP World Energy	Exajoules

Results and Discussion

There are eight variables in Table 2 where it shows that the data is normally distributed. The skewness test shows that all the variables are within less than 1 and -1. There are 52 years of observation and the study indicates a focus on time series data analysis. All of the variables exhibit an increasing pattern in Figure 2, with the exception of FDI, which shows unexpected fluctuations but still maintains an overall increasing trend. The correlation between the variables in the matrix is very high, as all the variables have a correlation value above 0.7 towards other variables.

The unit roots test is essential for determining whether the ARDL method is appropriate for this research. It is a common practice to spurious results and ignoring the structure break in the series of years (Rahman & Ahmad, 2019). As shown in Table 3, all the variables are not significant expect for FDI for both of the tests. After the first difference, the roots test clearly confirmed that all the variables for Phillips–Perron (PP) test is stationary at 1% significant level while Augmented Dickey Fuller (ADF) test also gained significant level for all the variables at 1% error except for the coal (significant at 5% error).

Table 2: Descriptive analysis and matrix correlations

Variables	**LCO_2**	**LGDP**	**LGDP2**	**LFDI**	**LHYDRO**	**LCOAL**	**LOIL**	**LGAS**
Mean	1.404	8.544	73.256	21.436	2.572	2.573	5.212	4.377
Median	1.617	8.675	75.257	21.974	2.740	2.956	5.461	5.001
Max.	2.109	9.316	86.788	23.646	4.439	5.606	6.132	6.149
Min.	0.347	7.513	56.450	18.359	0.822	-2.257	3.700	-2.508
Std. Dev.	0.592	0.519	8.796	1.476	0.977	2.424	0.754	2.053
Skew.	-0.334	-0.269	-0.195	-0.514	-0.098	-0.473	-0.461	-1.442
Kurtosis	1.544	1.887	1.839	2.174	2.326	2.008	1.847	4.443
Jarque-Bera	5.560	3.309	3.250	3.770	1.066	4.068	4.719	22.520
Prob.	0.062	0.191	0.197	0.152	0.587	0.131	0.094	0.000
Obs.	52	52	52	52	52	52	52	52
Variables	LCO_2	LGDP	LGDP2	LFDI	LHYDRO	LCOAL	LOIL	LGAS
LCO_2	1.000	0.986	0.984	0.836	0.888	0.959	0.990	0.904
LGDP	0.986	1.000	1.000	0.855	0.924	0.958	0.989	0.917
LGDP2	0.984	1.000	1.000	0.851	0.926	0.957	0.986	0.907
LFDI	0.836	0.855	0.851	1.000	0.767	0.808	0.844	0.816
LHYDRO	0.888	0.924	0.926	0.767	1.000	0.923	0.883	0.837
LCOAL	0.959	0.958	0.957	0.808	0.923	1.000	0.950	0.878
LOIL	0.990	0.989	0.986	0.844	0.883	0.950	1.000	0.935
LGAS	0.904	0.917	0.907	0.816	0.837	0.878	0.935	1.000

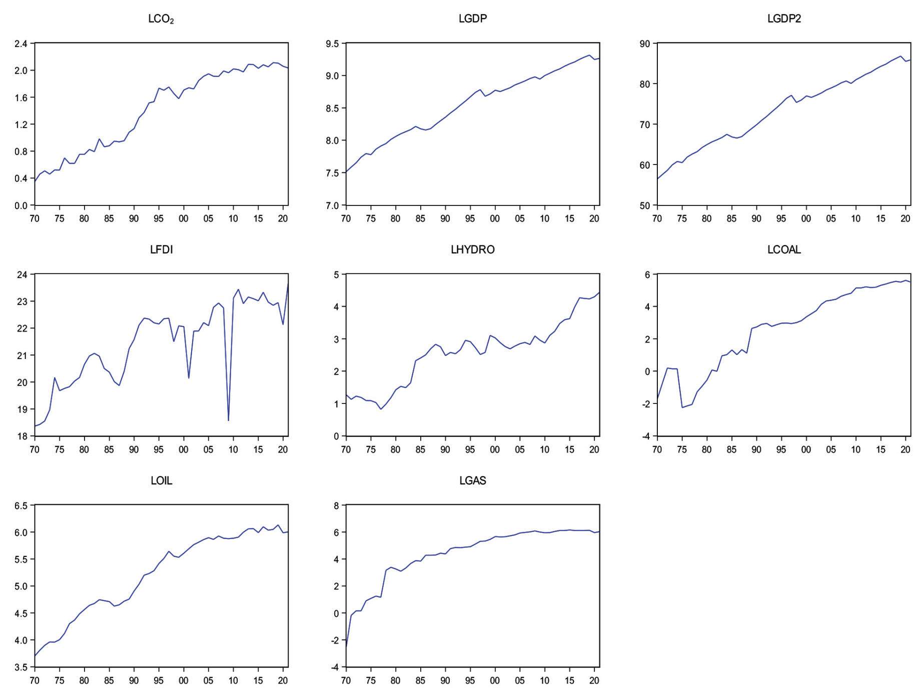

Figure 2: Variables pattern

Table 3: Unit roots test

Variables	PP		ADF	
	I (0)	I (1)	I (0)	I (1)
LCO_2	-0.861	-8.858***	-0.366	-9.003***
LGDP	-2.149	-6.029***	-2.158	-6.032***
LGDP2	-2.272	-6.220***	-2.357	-6.220***
LFDI	-5.505***	-17.366***	-5.505***	-7.798***
LHYDRO	-1.833	-5.806***	-2.190	-5.548***
LCOAL	-2.753	-7.489***	-1.781	-3.378**
LOIL	-0.703	-5.698***	-0.515	-5.645***
LGAS	-5.155***	-9.606***	0.113	-8.631***

Note: (*) Significant at 10%; (**) significant at 5%; (***) significant at 1%.

The bound test shown in Table 4 shows that there is cointegration in extended term for the economy and the energy usage towards the environment. The model lags (1,0,1,0,0,2,0,2) with maximum lag of two, indicating the F-test is 7.285 and significant at all levels of critical values. As the 0.7285 is more that upper bound for 1%, 5%, and 10% significant values, this means that there is extended-term correlation in the ARDL model.

Table 5 displays the ARDL near-term and extended-term outcomes. The near-term analysis revealed an inverted-U-shaped Kuznets curve when GDP is reported with a 1% error (6,706) and the GDP square has a 1% error with a negative value (-0.333). Thus, there is a pattern of increasing CO_2 emissions for GDP and decreasing CO_2 emissions for GDP square. A similar finding also occurred in the ARDL extended-term analysis, where the GDP was also found to be significantly positive (7.505) while the GDP square was found to be negatively significant at 1% (-0.394). Thus, it has been proven that both the cointegration for the ARDL approach in the short and extended term have the Kuznets curve, which exists with an inverted U-shape.

The energy usage from coal was also found to be significant at 10% with negative value (-0.037), which means that the fossil usage from coal to generate the electrical energy can give negative impact towards the environment. This is similar with the finding for the gas, as the result showed the usage of energy from gas to be significant and negative (-0.086), which means gas also contributes to pollution to the environment. However, this study also found that oil energy usage is positive sign, 0.308 (significant at 5%). The adjusted R-squared in ARDL (near-term) indicated high percentage at 99.3% and the F-statistic was 5.76.358, which is also significant at 1%.

Table 4: Bound test for ARDL extended-term

Model	Max. Lag	Lag Order	F-stat
$LNCO_2$ = f (LGDP, LNGDP2, LFDI, LHYDRO, LCOAL, LOIL, LGAS)	2, 2	(1, 0, 1, 0, 0, 2, 0, 2)	7.285 ***
F Statistics (Critical values)		Lower I (0)	Upper (1)
10%		1.920	2.890
5%		2.170	3.210
1%		2.730	3.900

Table 5: ARDL near term and ARDL extended-term

ARDL (Near-term)			ARDL (Extended-term)		
Variables	**Coefficient**	**t-Stat**	**Variables**	**Coefficient**	**t-Stat**
$\Delta LCO_{2(-1)}$	0.107	0.836	LGDP	7.505***	3.816
ΔLGDP	6.706***	3.365	LGDP2	-0.394***	-3.775
ΔLGDP2	-0.333***	-3.048	LFDI	-0.014	-1.130
$\Delta LGDP2_{(-1)}$	-0.019	-1.374	LHYDRO	-0.054	-1.497
ΔLFDI	-0.012	-1.092	LCOAL	0.073***	4.997
ΔLHYDRO	-0.049	-1.495	LOIL	0.345**	2.377
ΔLCOAL	0.019	1.157	LGAS	-0.089***	-2.961
$\Delta LCOAL_{(-1)}$	-0.037*	-1.821	C	-35.027***	-4.040
$\Delta LCOAL_{(-2)}$	0.083	5.395			
ΔLOIL	0.308**	2.199			
ΔLGAS	-0.028	-1.000			
$\Delta LGAS_{(-1)}$	0.035	1.152			
$\Delta LGAS_{(-2)}$	-0.086***	-4.044			
C	-31.296***	-3.500			
Adjusted R-squared	0.993				
F-statistic	576.358***				

In the ARDL (extended-term), the results identified that those three important variables are significant. The energy usage from gas was -0.089 (significant at 1% error), meaning in the long period, there is negative impact of energy generated by gas to the environmental deterioration. However, the extended-term cointegration of ARDL also indicated that energy usage from coal and oil has a positive sign and is statistically significant, with respective values of 0.073 and 0.345. The short and extended-term ARDL were not clearly able to impact the environment through FDI and energy usage from hydro, as both variables were reported to be not significant in both cointegration.

Table 6 indicates the bound test for non-linear ARDL in extended-term approach. The maximum lag is two with the lag order (1, 1, 1, 0, 2, 1, 0, 2, 0, 0, 2, 1) finds that the F-test is 5.999. This shows that the F-test is higher than upper bounds value at 10% (2.77), 5% (3.04), and 1% (3.61). Thus, there are extended-term cointegration between the Malaysia economy and the renewable and non-renewable energy usage towards the CO_2 emissions.

Table 6: Bound test for NARDL extended-term

Model	**Max. Lag**	**Lag Order**	**F-stat**
$LNCO_2$ = f (LGDP, LNGDP2, LFDI, LHYDRO, LCOAL, LOIL, LGAS)	2, 2	(1, 1, 1, 0, 2, 1, 0, 2, 0, 0, 2, 1)	5.999 ***
F-satistics (Critical values)		Lower I (0)	Upper (1)
10%		1.76	2.77
5%		1.98	3.04
1%		2.41	3.61

Table 7 shows cointegration of the non-linear ARDL approach in short and extended-term of the Malaysia economy condition, the energy usage of renewable (hydro), and non-renewable fossil energies (coal, oil, and gas) towards the environment proxy as CO_2 emissions. The results of NARDL for near term found that the income was significant, as the GDP was significant at 5% and positive sign, which was 16.984.

Meanwhile, the GDP square showed a negative value (-1.006) and was significant at 5%. These results are also similar to the NARDL extended-term, as the GDP and GDP square were both significant at 1% error, with values of 16.111 and -0.858, respectively. These findings proved that the Malaysian economy is making good environmental progress, as CO_2 emissions are increasing in the early stages of the economy and decreasing in the later stages. In both short and extended-term cointegration, the Kuznets curve is clearly inverted U-shaped.

The FDI for NARDL in the short and extended-term is negative with a 5% significance level, -0.033 and -0.034, respectively. This means that FDI inflows to Malaysia are harmful for the

Table 7: Non-linear ARDL near term and non-linear ARDL long run

Non-linear ARDL (Near-term)			**Non-linear ARDL (Extended-term)**		
Variables	**Coefficient**	**t-Stat**	**Variables**	**Coefficient**	**t-Stat**
$\Delta LCO_{2(-1)}$	0.035	0.246	LGDP	16.111***	4.460
ΔLGDP	-1.445	-0.197	LGDP2	-0.858***	-4.298
$\Delta LGDP_{(-1)}$	16.984**	2.213	LFDI	-0.034**	-2.395
ΔLGDP2	0.179	0.421	$LHYDRO_{\_POS}$	0.027	0.366
$\Delta LGDP2_{(-1)}$	-1.006**	-2.240	$LHYDRO_{\_NEG}$	-0.045	-0.392
ΔLFDI	-0.033**	-2.225	$LCOAL_{\_POS}$	0.045	1.485
$\Delta LHYDRO_{\_POS}$	-0.178***	-2.826	$LCOAL_{\_NEG}$	0.072**	2.299
$\Delta LHYDRO_{\_POS(-1)}$	0.042	0.539	$LOIL_{\_POS}$	0.094	0.439
$\Delta LHYDRO_{\_POS(-2)}$	0.162**	2.298	$LOIL_{\_NEG}$	0.142	0.436
$\Delta LHYDRO_{\_NEG}$	0.555***	3.442	$LGAS_{\_POS}$	-0.163***	-3.581
$\Delta LHYDRO_{\_NEG(-1)}$	-0.598***	-3.176	$LGAS_{\_NEG}$	0.223	1.299
$\Delta LCOAL_{\_POS}$	0.043	1.540	C	-71.776***	-4.526
$\Delta LCOAL_{\_NEG}$	0.047	1.290			
$\Delta LCOAL_{\_NEG(-1)}$	-0.074*	-1.829			
$\Delta LCOAL_{\_NEG(-2)}$	0.096***	3.291			
$\Delta LOIL_{\_POS}$	0.091	0.443			
$\Delta LOIL_{\_NEG}$	0.137	0.438			
$\Delta LGAS_{\_POS}$	-0.070	-1.679			
$\Delta LGAS_{\_POS(-1)}$	0.009	0.272			
$\Delta LGAS_{\_POS(-2)}$	-0.095**	-2.589			
$\Delta LGAS_{\_NEG}$	-0.372	-1.275			
$\Delta LGAS_{\_NEG(-1)}$	0.587**	2.221			
ΔC	-69.229***	-3.742			
Adjusted R-squared	0.994				
F-statistic	367.930***				

environment, as the cointegration between FDI and CO_2 emissions is negative in both short and extended-term approaches. The energy usage variables have positive and negative side points of view to identify a deeper sign of the selected variables towards CO_2 emissions.

In the extended-term, the NARDL indicates that only two variables have significant values, which are the usage of coal and gas energy. The results indicated that energy usage from coal was 0.072, which means that a decrease in coal usage will have a positive impact on the environment. Meanwhile, the increasing energy usage from gas (-0.163) will have a negative impact on the environment.

The NARDL near-term model shows a high adjusted R^2 value of 0.994 and yields notable findings, including hydro energy usage exhibiting both positive and negative effects. These hydro usages have two significant findings for positive side views, -0.178 and 0.162. While increasing the stage of hydro energy usage has a negative impact on the environment, it will eventually overcome and produce a positive impact on the ecosystem. The reduction of hydro energy usage has the opposite effect at first (0.555) and then has a negative impact on the environment (-0.598). This result is similar with study by Jahanger *et al*. (2022) as the hydro energy has impact to reduce the CO_2 emissions in Malaysia.

The other significant finding is the reduction of energy from coal, specifically -0.074 and 0.096, respectively. Thus, this indicates that by decreasing coal energy usage, CO_2 emissions will be reduced. The usage of other non-renewable energy also indicates the same finding as the decrease in gas energy usage. In the first stage, it is -0.372 and eventually, it reaches 0.587. The increase in gas energy usage is significant, with a value of -0.095. This indicates that there will be a negative impact, leading to environmental deterioration. Similar finding was also found by Hanif (2018), Ridzuan *et al*. (2020), and Akhtar *et al*. (2022), as the consumption of fossil energy increase the CO_2 emissions and harm the environment in Malaysia.

The diagnostic test in Table 8 shows the robustness of the ARDL and NARDL results. Data is normally distributed in ARDL and non-linear ARDL models, as the F-test for Jarque-Bera are 0.097 and 0.340, respectively and the Ramsey RESET tests are 0.649 and 0.2555, respectively, where all values are more than 0.05. The LM test for serial correlation shows clear from bias within the times series as the ARDL (0.167> 0.05) and the non-linear ARDL (0.118 > 0.05).

There is also no heteroskedasticity problem in either model, as the tests of Breusch-Pagan-Godfrey, Harvey, Glejser, and ARCH all show values that are greater than 0.05 significant error. Figure 3 also shows that the CUSUM test and CUSUM square are stable within 5% significant error for the models. Thus, the models ARDL (1, 0, 1, 0, 0, 2, 0, 2) and non-linear ARDL (1, 1, 1, 0, 2, 0, 0, 2, 1) are robust, stable, and free of bias.

Table 8: Diagnostic test for ARDL and NARDL (SR and LR)

Diagnostic Test	ARDL F-stat	NARDL F-stat	Results
Jarque-Bera	4.664 (0.097)	2.156 (0.340)	Normal distributed
Ramsey RESET Test	0.211 (0.649)	1.355 (0.255)	Normal distributed
Serial Correlation LM Test	1.888 (0.167)	2.344 (0.118)	No serial correlation problem
Heteroskedasticity Test:			
Breusch-Pagan-Godfrey	0.445 (0.941)	0.322 (0.996)	
Harvey	1.426 (0.195)	1.702 (0.097)	No heteroskedasticity problem
Glejser	0.523 (0.895)	0.598 (0.888)	
ARCH	0.279 (0.600)	0.650 (0.424)	

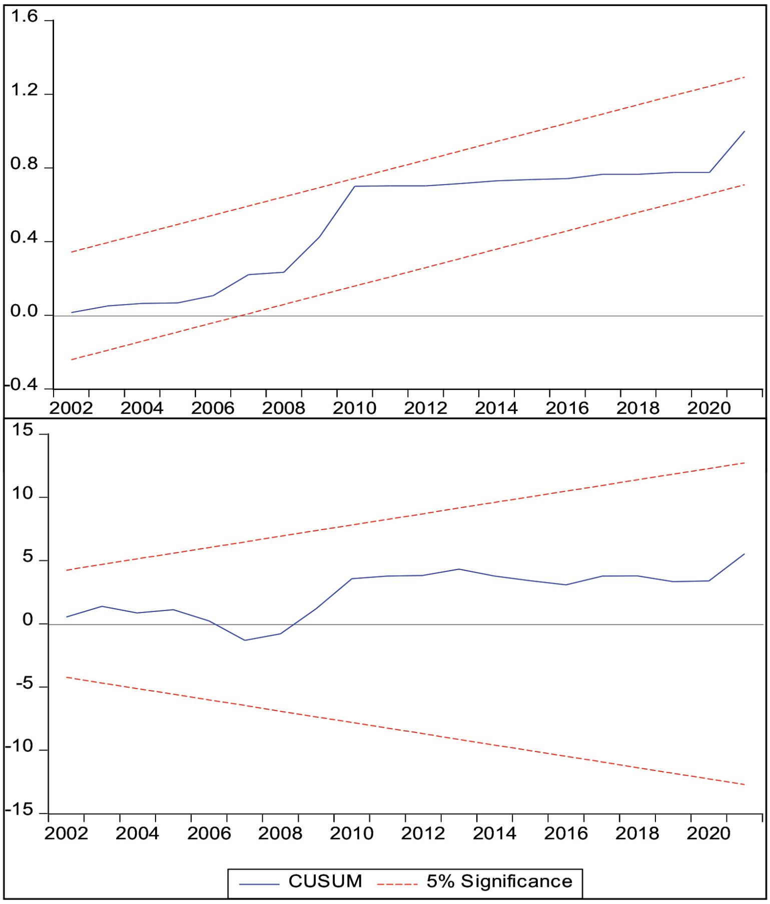

Figure 3: CUSUM and CUSUM squares test

Policy Implication

The world is changing rapidly and Malaysia cannot afford to fall behind in terms of global progress. The urgent need for electricity usage grows year after year in tandem with population growth and the advancement of heavy industries. Environmental pollution caused by the use of fossil fuels has long been a concern in the context of societal progress. Thus, this leads to the issue of transforming fossil-based electricity into clean and renewable energy.

Malaysia possesses significant potential for facilitating the transition towards sustainable electricity. Malaysia is a tropical country known for its abundant water resources, with an annual precipitation average of 2,400 mm (Koid *et al*., 2022). As a result, Malaysia has a history of utilising hydroelectric power and has several dams, including the Bakun and Murum Dams in Sarawak, the Kenyir Lake Dam in Terengganu, the Temenggor Dam in Perak, and the Pedu Dam in Kedah.

Apart from relying on natural energy sources such as hydropower, Malaysia has great potential for harnessing solar energy as a sustainable energy supply for household usage. The hot and humid climate of Malaysia offers many advantages, its consistently hot weather potentially provides clean solar-based energy. The "Large Scale Solar Policy (LSS) Programme" is regarded as a commendable government initiative, although the level of coercion associated with this policy remains relatively low. The reason for this is that the cost of installing solar panels is high; nevertheless, it has the ability to achieve extended-term savings and reduce environmental pollution. The new innovation for the latest smart house infrastructure is expected to include solar panels, which will absorb the heat from the sun and convert it into electrical energy. Thus, the idea for the future generation is to not be highly dependent on fossil-based electricity.

The transformation towards clean and sustainable energy will aid in the protection of our planet and the strengthening of Malaysian economies. The policy, known as the "Feed-in Tariff (FiT) Programme" provides sustainable energy operating firms in Malaysia with a fixed premium rate tariff. The primary objective of this policy is to incentivise the allocation of capital towards renewable energy initiatives. It also aims to ensure a predetermined and assured financial gain for producers engaged in renewable energy production. Therefore, it is crucial that the Malaysian government plays a significant role in implementing green policies. These policies aim to raise consumer awareness and ultimately, accomplish Sustainable Development Goal 7 by the year 2030.

Conclusions

The ambitions of Malaysia for economic development demonstrate the commitment of the country to renewable energy in order to achieve the goals of SDG 7. The results conclude that the Kuznets curve with its inverted U shape in the short and extended-term indicates that Malaysia is moving in the right direction towards sustainable and clean energy. The study indicates that the environment is significantly harmed by fuel energy usage while it is not able to prove that hydro energy reduces CO_2 emissions in the short and long run. However, the non-linear ARDL has proven that the cointegration of renewable and non-renewable energy towards the environment gives hope that hydro energy can reduce CO_2 emissions.

Therefore, Malaysia has the potential to achieve SDG7 by 2030 by continuously increasing efforts to enhance renewable and clean energy. The limitation of this study is that it only focuses on hydro as the renewable energy. Malaysia's geographic location, which is endowed with plenty of sunshine and long coasts, offers enormous potential for harnessing solar and wind energy. Therefore, there is still potential future study on other renewable energy such as solar power, wind power, biomass, and biogas to be explored using the same theory.

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Conflict of Interest Statement

The authors declare that they have no conflict of interest.

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