Indonesia: Comparison Between the Most Consumption of Renewable and Non-Renewable Energy Toward CO_2 Emissions

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DOI: https://dx.doi.org/10.47772/IJRISS.2025.90500025

Received: 30 March 2025; Revised: 04 April 2025; Accepted: 08 April 2025; Published: 28 May 2025

ABSTRACT

Indonesia is a developing country with a major opportunity for economic expansion. As a result, Indonesia is experiencing an increasing pattern of electricity consumption and CO_2 emissions. However, the world, including Indonesia, has agreed to transform non-renewable energy sources into clean energy and is progressively making efforts to achieve SDG7, which aims to generate sustainable energy by 2030. Hence, the purpose of this study is to examine the effects of power consumption derived from non-renewable energy sources (specifically fuel) and renewable energy sources (specifically hydroelectricity) on CO_2 emissions in Indonesia. Indonesia is also known as the fourth largest population in the world. Therefore, this study also includes urban and total population as independent variables. The Autoregressive Distributed Lag (ARDL) cointegration analysis technique is used in this study to examine both the short and long run for the period of years from 1980–2021. The finding of this study shows that CO_2 emissions in Indonesia are rising as a result of economic activity, population growth, and the high dependence on fossil fuels as electrical energy.

Keywords: CO_2 emissions, electricity, non-renewable, renewable, sustainability

INTRODUCTION

In There is a growing concern regarding the increasing carbon emissions in Indonesia, as the country's economic development advances. In their study, Nihayah et al. (2022) emphasise the intricate interrelationships among urbanisation, economic growth, foreign investment, deforestation, government spending, and CO_2 emissions. The study indicates that eco-friendly urbanisation, focused investments, strategic shifts towards renewable energy, and well-constructed regulatory regulations are necessary for attaining sustainable growth and lowering carbon emissions. Therefore, the issue of Indonesia's CO_2 emissions presents a formidable challenge, yet it remains within the realm of possibility. If the problem is addressed from a variety of different perspectives, such as changing energy policy, preserving forests, innovating in human capital development, and improving waste management, it is possible for the country to move towards a future of sustainable growth, decreased carbon emissions, and greater wellbeing (Prasetyani et al., 2021).

Numerous studies have discovered a conspicuous correlation between the consumption of fossil energy and the emissions of CO_2, leading to an intricate predicament as the economic development of Indonesia itself adds to the degradation of the environment (Mohamad et al., 2023). Despite all of these environmental concerns, the significance of human progress cannot be overlooked by the country. Bashir et al. (2019) remind us that increasing our human capital and fostering innovation are not incompatible with the reduction of CO_2 emissions. According to Cahyono et al. (2022), coal power plants, especially those located in Java, Indonesia, are notable sources of pollution, and it is anticipated that their CO_2 emissions will rise until 2050. There is a similar concern regarding the scenario in West Sumatra, Indonesia. The issue becomes alarming when the levels of CO_2 continue to rise above 400 ppm, which indicates severe environmental consequences (Cahyono et al., 2022). Ordonez et al. (2022) point out that Indonesia does not have to continue relying so heavily on carbon, as there exist other studies. By switching to renewable energy sources has the potential to reduce CO_2 emissions by approximately 120 million metric tonnes from the anticipated 470 million metric tonnes in 2040 (Ordonez et al. 2022).

According to Ridzuan et al. (2020), Indonesia's path to economic advancement has been tragically marked by significant toward harming the environmental, following a pattern known as the Environmental Kuznets Curve. The Kuznets theory, also referred to as the Environmental Kuznets Curve (EKC), is a conceptual framework that provides a conceptual description of the relationship between increasing levels of revenue and increasing levels of environmental deterioration.

Kuznets (1955) stated that there exists a connection between economic growth and income equality, which takes the shape of an inverted U. This person is the one after whom this word is named. Grossman and Krueger (1991) examined environmental factors for the first time and formulated a theory known as the inverted U-shaped theory. In their study, the researchers examined the data for 42 countries and discovered that the levels of two out of the three air pollutants, namely sulphur dioxide and "gas carbon-smoke," increase when the national income is low and decrease when it is high. However, in the case of Indonesia, the theory demonstrates that environmental damage increases in direct proportion to economic growth. The concern lies in the damage caused by the use of "dirty energy" despite the partial mitigation of this trend through access to cleaner technology enabled by international trade (Sugiawan & Managi, 2016). The problem of overreliance on fossil fuels extends beyond energy concerns, as it stands as a primary contributor to climate change. In their study, Raihan et al. (2022) emphasise the pressing requirement for innovative methods, technological breakthroughs, and courageous policy decisions. These measures are necessary to separate the growth of Indonesia's economy from the harm it inflicts on the environment.

Despite all of these environmental concerns, the country cannot overlook the significance of human progress. Bashir et al. (2019) remind us that increasing our human capital and fostering innovation are not incompatible with reducing CO_2 emissions. According to Raihan et al. (2022), the restoration of the environment can be facilitated by utilising renewable energy sources, advancing cutting-edge technologies, and effectively managing forests. In contrast, Khusna and Kusumawardani (2021) propose the integration of energy resources and the increased utilisation of renewable energy as viable solutions.

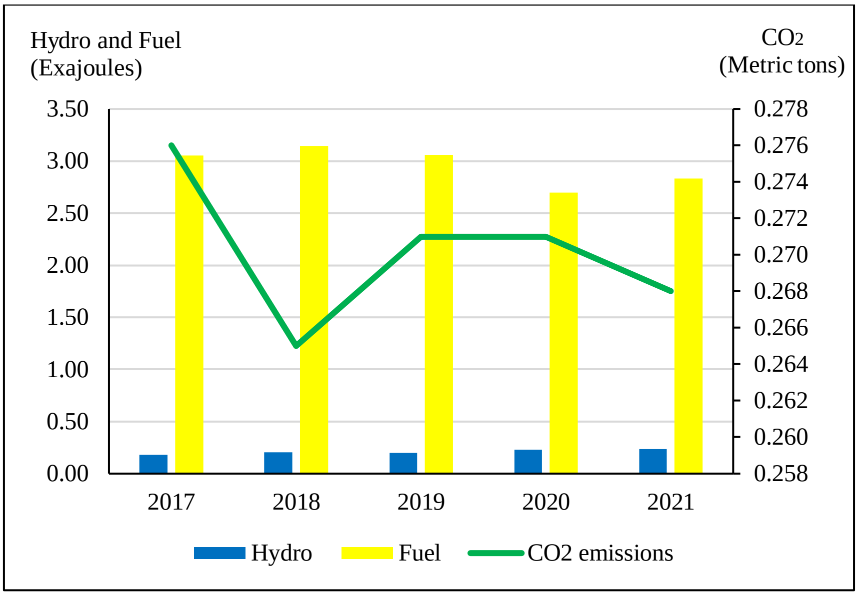

Figure 1. Compare of CO_2 emissions, hydro and fuel energy consumption

Source: BP World Energy

Figure 1 depicts the notable disparity between the utilisation of fossil energy and renewable energy in Indonesia during the period spanning from 2017 to 2021. Praise should be given to Indonesia for their fuel energy consumption rates, which provide an overview of a decreasing trend from 2017 to 2020. The consumption rates decreased from 3.05 to 2.70 exajoules during this period. However, by 2021, the consumption rates increased once again to 2.83 exajoules. The CO_2 emissions also exhibit a decreasing pattern from 2017 to 2019 and from 2020 to 2021, while increasing from 2018 to 2019. Specifically, the emissions increased from 0.265 to 0.271 metric tonnes of CO_2 emissions. The consumption of hydro energy is showing a significant difference compared to fossil fuel, and the volume of the trend remains static. This problem needs to be taken seriously because the excessive use of fossil energy will have a negative impact on the environment. Therefore, this study aims to examine the effects of power consumption derived from non-renewable energy sources (specifically fuel) and renewable energy sources (specifically hydroelectricity) on CO_2 emissions in Indonesia.

LITERATURE REVIEW

Environment Awareness of Global Warming Phenomena

Global warming is an effect from the long and continuous activities of industrialization and other human activities (Intergovernmental Panel on Climate Change, 2001), from the emissions of greenhouse gases (GHGs). The GHGs are emissions from fossil fuels and other non-renewables resources, such as coal (Moriarty & Honnery, 2014). This causes climate change, which is defined as a systematic change in average conditions over time (Prasad & Mkumbachi, 2021), in particular increase in the global temperature, which will eventually cause sea level increase due to glacial ice flow and melting with a disastrous impact of more frequent and severe natural disasters. In addition, the atmospheric concentrations of carbon dioxide (CO_2) have also increased and continue to rise annually by approximately 2.0 parts per million (ppm) (Moriarty & Honnery, 2014). Therefore, climate change poses a risk and has the potential to become a global disaster if not mitigated. This is due to the fact that the survival of human life and biodiversity relies on a conducive environment (Prasad & Mkumbachi, 2021).

There are claims that climate change is a normal occurrence, but recent changes, such as the rise in global temperature, have been more pronounced. Due to a lack of concern and evidence (Veal & Mouzas, 2010) and no pricing of the environment as a carbon sink, this phenomenon has worsened. Prior to the emergence of global environmental concern, environmental resources were viewed as being without cost. Polluting corporations were not required to pay for externalities such as air and water pollution (Veal & Mouzas, 2010).

Despite the awareness of the disastrous implications of global warming, the timing factor, in which the disaster was perceived as being far off, discouraged investment in cleaner technology and hindered the formulation and enforcement of appropriate mechanisms to ensure that those responsible for pollution are held accountable for their actions. Furthermore, mitigation costs were considered as expensive and incurred higher cost of production (Veal & Mouzas, 2010). Hence, initially, there had been skepticisms and rejection of climate change by many capitalist ventures, multi-national companies, and even countries who did not want to ratify the Kyoto Protocol.

Recently, there has been a change where there is less conception regarding the conflict between profit-making and environmental stewardship (Olson, 2009). The business sectors understand their role in curbing GHG emissions, and there is currently a clearer model to do so. This model includes schemes such as the Clean Development Mechanism (CDM), the Emission Trading System (ETS), carbon tax, carbon credit, and others. According to Cadez and Guilding (2017) despite the difference between climate change abatement strategies, across carbon intensive sectors, they are relatively homogenous within them, making it is easier for the business sector to willingly participate and implement in such strategies. It is common for the business sector to embrace green policy and integrate it in their production, such as by identifying the impacts of externalities at all level by conducting Life Cycle Analysis (LCA) to calculate their carbon footprint (Olson, 2009).

Dell is an example of a company that declares itself to be carbon neutral through strategies to convert and eventually increase renewable energy purchasing and usage for production. Exxon is another company that is sceptical of climate change but began developing and implementing strategies to mitigate the risk of climate change in 2007 (Veal & Mouzas, 2010). According to Olson (2009), the positive response and actions from the business sector was due to increasing evidence experienced and extreme predictions in the future, based on empirical previse simulation and projection. Global warming is a transboundary problem, which needs to be addressed by all, especially by the contributors of GHGs (Olson, 2009). However, according to Nartey (2018) only a minimal reduction in the total amount of GHGs emissions has been achieved by the business sector.

The Impacts of Global Warming

Olson (2019) predicted that global warming will cause adverse effects globally. According to Saxena et al.

(2022) the impacts of global warming include droughts, water scarcity, extreme rainfall, flooding, species loss, biome shifts, deforestation and disease. However, Olson (2009) also stated that the adverse effects have caused an alarm among the people, leading to public pressure with national security and safety concerns due to natural resources and raw material scarcity. Apart from environmental impacts, other socio-economic impacts arise due to changes in weather patterns, which affect the distribution of fresh water and could decrease rain-fed rice yields, reduce crop yields, causing food insecurity and eventually leading to hunger and poverty (Olson, 2009). Public pressure is also commonly associated with the concern to endemic and endangered species, such as the polar bear and Orang Utan, which has positive impact world-wide and help to push environmental improvement (Veal & Mouzas, 2010).

As climate change is transboundary and a common global problem (Veal & Mouzas, 2010), the implication of it, especially in terms of resource scarcity can cause national and international security concerns (Olson, 2009). Countries might introduce protectionist economic barriers, being the main reason for United States of America (USA) to reject ratifying the Kyoto Protocol in 1991. Scarcity in resources can cause public unrest like riots, corruption, sanctions and even military actions to protect sovereign borders and natural resources (Olson, 2009). On the other hand, severe weather patterns like flood, fires, hurricane and etc. will pose safety risk to human and properties (Olson, 2009).

Issues of CO_2 Emissions in Indonesia

The global scenario reveals that the world is divided into three perspectives on climate change: the European Union (EU), the USA, and the developing countries. Since ratifying the Kyoto Protocol in 1991, the EU has championed and supported the climate change agenda. The European Emissions Trading Schemes have been set up, and targets for emission reductions have been committedly set (Veal & Mouzas, 2010). At a global level, the EU is leading on the issue of climate change and is willing to accept different standards of other countries, especially the developing countries (Veal & Mouzas, 2010).

Despite the USA not ratifying the Kyoto Protocol, there have recently been positive initiatives as a result of public pressures for the government to take action in addressing CO_2 emissions (Veal & Mouzas, 2010). The USA has adopted a protectionist approach due to cost issues, as it is one of the largest emitters of greenhouse gases. Furthermore, there was dissatisfaction with the fact that other giant economic countries, such as China and India, were not required to reduce their emissions during that time.

Regarding the developing countries, the majority of them exhibit apprehension towards taking action on climate change, and there persists a sense of conflict between pursuing profit and practising environmental stewardship. According to Han et al. (2022) and Mohamad et al. (2023), developing countries have been cautious in adopting policies related to carbon trading. This caution stems from the fact that the conversion to renewable energy can be expensive, resulting in increased production costs. Consequently, there is a concern that this may lead these countries to fall into the trap of energy insecurity. The bigger nations, such as Russia, China, and India, are focusing more on energy efficiency rather than setting and working towards achieving targets to reduce greenhouse gas emissions (Veal & Mouzas, 2010; Mohamad & Ab-Rahim, 2024a).

Developing countries like Indonesia still experiences environmental degradation in the form of externalities in their pursuits of economic progress and there is also lax of environmental regulation (Ibrahim & Rizvi, 2015). Yet, Indonesia, being a low-lying country with many islands is ranked as in the top-third of countries in terms of climate risk, with high exposure to flooding and extreme heat (Ismail & Go, 2021). Indonesia is vulnerable to sea-level rise, and also ranked fifth highest in the world population inhabiting lower elevation coastal zones. Therefore, it is urgent for Indonesia to take action on climate change, or its population will face permanent flooding that could affect more than 4.2 million people (Ismail & Go, 2021; Syamsidik et al., 2021). Similar to other vulnerable regions of the world, Indonesia is at risk of food insecurity due to drought and rising temperatures, which will have a negative impact on the welfare of the population, particularly the poor and marginalised (Hastuti et al., 2021).

Indonesia is Too Dependent on Fossil Energy

Indonesia, which stands among the world's largest economies, faces a challenging balancing act. Therefore, it must discover a means to fuel its economic engine while also managing the consequences of its significant dependence on fossil fuels. The problem has been exacerbated by Indonesia's transition from being an oil-exporting country to becoming a net importer, as stated by Ichsan et al. (2022). Indonesia's transition from being an oil-exporting nation to a net importer is more challenging due to the significant reliance on the national oil company Pertamina to support the economy.

The fact that Indonesia relies so heavily on non-renewable energy sources complicates the relationship between energy consumption and carbon emissions, which is already intricate. According to a study by Sasana and Aminata (2019), Indonesia's reliance on the energy sector contributes to the country's greenhouse gas emissions. The enormous impact of energy consumption and free trade on economic growth is another aspect driven by fuel energy. This is supported by Chontanawat (2020), who states that as the economy grows, so does energy demand.

A plethora of studies also conducted related to Indonesia and other ASEAN countries, examining the balance between economic growth and environmental sustainability in the region. According to Farabi (2019), the path of economic expansion often leads to greater energy consumption and carbon emissions. This is especially true in nations like Indonesia, where fossil fuels dominate the energy landscape. Bashir et al. (2019) reach the same conclusion as before, which is that there is a correlation between these parameters and GDP. This connection has been confirmed by these researchers.

Broadening the scope to other ASEAN countries, Vo et al. (2019) found a relationship between several factors including economic growth, energy consumption, renewable energy use, carbon emissions, and population growth. The findings underscore the need for a shift towards renewable energy. The similar finding by Darwanto et al. (2019) emphasises the link between economic growth and carbon emissions, thereby highlighting the necessity for greener economic strategies.

Dilemma of Renewable and Non-Renewable Energy in Indonesia

The path for Indonesia to adopt cleaner energy options, such as biodiesel, has not been easy. In their study, Farobie and Hartulistiyoso (2022) delve into the exploration of the compulsory biodiesel policy. They highlight its potential for job creation and significant foreign exchange savings. However, they also emphasise the presence of substantial socio-political and environmental hurdles that require direct attention and resolution. However, despite these challenges, promise is held by renewable energy.

Sinaga et al. (2019) and Chien (2022) shed light on the crucial role that Indonesia's economy plays through both renewable and non-renewable forms of power production. These studies urge increased government support for renewable energy sources, which, in contrast to non-renewable sources, can contribute to improving the quality of the environment. However, as Yana et al. (2022) point out, the transition to renewable energy sources is not simple. In Indonesia, policy reforms to encourage the use of alternative energy sources are urgently needed, as the country's energy demands continue to rise despite a stable oil supply.

Saudi et al. (2019) take the discussion a step further, suggesting that renewable and non-renewable electricity generation, along with carbon emissions, play a significant role in Indonesia's economic growth. In contrast, Raihan et al. (2022) present a more optimistic outlook. They suggest that through the utilisation of renewable energy, technological innovation, and the improvement of agricultural productivity, Indonesia can effectively counteract the adverse impacts of carbon emissions. Prawoto (2020) and Kurniawan et al. (2022), highlight the dual role of carbon emissions in Indonesia's economic growth. The study advocates for the adoption of green economic models. Munir et al. (2020) found that energy conservation initiatives do not necessarily impede economic growth in Indonesia.

Zeeshan et al. (2022) address the issue of trade liberalization and its double-edged impact. While it has fueled economic growth, it has also increased energy consumption and carbon emissions. Anwar and Elfaki (2021) found similar trends in Indonesia, with trade openness contributing to environmental degradation. However, there are study that show the opposite finding and underscores the importance of renewable energy in reducing carbon emissions while promoting economic growth in ASEAN countries (Ansari, 2022).

Kuznets Theory Cases in Indonesia

A multitude of studies have applied the theory of Kuznets to examine the quality of the environment in relation to economic development in Indonesia. The Kuznets curve hypothesis assumes that the relationship between wealth and environmental deterioration is not linear, but instead takes the shape of an inverted U (Mu'mina et al., 2024). This indicates that environmental degradation, specifically CO_2 emissions in this example, may initially increase with a country's level of prosperity. However, once it reaches a turning point, it begins to decline as the country's level of income rises further. This statement demonstrates that there exists a positive association between the variables during the initial stages of development, which subsequently transforms into a negative relationship during the later stages of development (Miah et al., 2010).

Regarding the hypothesis of the Environmental Kuznets Curve (EKC), Kisswani et al. (2019) conducted a study on this phenomenon in ASEAN-5 countries from 1971 to 2013. Their findings revealed nuanced results. They observed a significant U-shaped relationship between income and environmental degradation in Thailand. Additionally, through Granger Causality tests, they discovered a bidirectional link between CO_2 emissions and GDP in both Thailand and Malaysia. Similarly, Robbi et al. (2020) studied Indonesia from 1969 to 2016, illustrating a U-shaped curve but not confirming an EKC, pointing to the crucial role of trade openness, energy consumption, and demographic factors in the discourse of environmental sustainability.

Furthermore, Umaroh (2019) examined the correlation between education and carbon dioxide emissions in Indonesia from 1976 to 2016 by employing the EKC framework. She discovered that there existed a U-shaped relationship in the short term, as well as an inverse U-shaped relationship in the long term. These findings both confirmed and contradicted the traditional EKC hypothesis. In contrast, Darwanto et al. (2019) discovered inadequate evidence of the EKC in Indonesia. This is despite the countries per capita GDP, energy use, and CO_2 emissions displaying a notable linear relationship.

Prasetyanto and Sari (2021) findings in Indonesia showed an inverted U-shaped association between economic expansion and environmental deterioration, supporting the EKC theory over the medium and long terms. Intriguingly, Elfaki and Heriqbaldi (2023) investigated how industrialization affected the EKC in Indonesia, supporting the EKC hypothesis while also demonstrating how industrialization reverses this relationship and emphasizing the transformative effects of industrialization and financial development on environmental sustainability.

Alam et al. (2016) conduct empirical studies using ARDL linear and non-linear regression to determine the relationship between income, trade openness, and energy consumption and CO_2 emissions. For both the ARDL linear and quadratic approaches, the results show a significantly positive relationship with CO_2 emissions in Indonesia. A similar approach was used with different time series data from 1975 to 2017. The CO_2 emissions show a significant trend towards fossil fuels, and the decrease in CO_2 emissions indicates that the Kuznets curve does indeed exist in Indonesia (Kusumawardani & Demi, 2020).

There are also studies that report having a negative pattern for EKC. In the context of Indonesian districts 1992 to 2017, a study conducted by Yusuf et al. (2021) tested the theory, revealing a complex connection that both aligns and deviates from Kuznets' hypothesis at different stages of development. The complexity mentioned was reflected in a study conducted by Ridzuan et al. (2021). The study discovered a financial Kuznets Curve in the economies of Malaysia, Thailand, Indonesia, and the Philippines. This finding demonstrates a mixed relationship between financial development and income inequality. Some studies also indicate negative results for EKC. The investigation of the EKC for deforestation in Indonesia in 2021 revealed that tree cover loss worsens in the early stages of development but improves once a certain level of GDP per capita is reached (Adila et al., 2021). Similar finding found when examined the hypothesis of EKC in Indonesia and discovered that it was invalid in both the short and long-run for Indonesia because GDP per capita had a substantial positive impact on CO_2 emissions (Yunita et al., 2023)

Further research was conducted to investigate renewable energy in order to examine the effect of Kuznets' curve in Indonesia. Sugiawan and Managi (2016) conducted the ARDL to identify the cointegration of renewable energy sources over a 40-year observation period (1971–2010) with a focus on the Indonesia Kuznets curve. The research indicated that there is a positive correlation between CO_2 emissions and income level. Additionally, it was clear that the long-run income elasticity had reduced over time. Other's study, examinate the non-renewable and renewable energy consumption within period of 1991 to 2016, able to proven there is inverted-U shaped in ASEAN by using the ecological footprint compare toward the CO_2 emission that has invalid results for the Kuznets curve (Ansari, 2022).

Massagony and Budiono (2023) debunked the EKC theory for CO_2 emissions in Indonesia by showing that emissions increased continuously with income while also demonstrating that emissions were reduced through the use of renewable energy and legislation pertaining to forests. Additionally, Bekun et al. (2021) investigation of the EKC phenomenon in the E7 economies from 1995 to 2016 confirmed the EKC hypothesis that environmental health is improved by economic globalization and renewable energy sources, underscoring the necessity for improved institutional quality and a shift to renewable energy sources. The study that investigated the EKC hypothesis in 11 developing nations between 1992 and 2014 yielded a similar result. It showed a long-term inverse U-shaped link between CO_2 emissions and GDP per capita for the overall sample. However, it produced conflicting results for specific nations, as stated by Ahmad et al. (2021).

Numerous studies have already addressed environmental issues; however, this study concentrates on Indonesia, which has the fourth-largest population in the world, and compares the most widely used renewable energy (hydro) and the most widely used fossil energy, which is the fuel energy, toward the CO_2 emissions from 1980 to 2021.

METHODOLOGY

The annual time series data has been gathered from the database of World Development Indicators, Our World in Data, and BP statistic, during the period of time spanning from 1980 to 2021 for the purpose of empirical analysis. Table 1 contains explanations of the variables as well as the data sources for those variables. As LCO2 stands for carbon dioxide emission (CO_2 metric tons per capita), LGDP and LGDP2 stand for GDP per capita and GDP square per capita respectively, with constant 2015 USD. The LFUEL represents fuel energy consumption, LHYDRO represent for energy consumption based on hydro, LURBAN represent the population in the urban area and LTOPOP represent for total population in Indonesia. To achieve a more precise result, all variables are calculated in logarithms.

Table 1. Variables table

Variable	Symbol	Data base	Unit
CO_2 Emissions Per Capita	LCO2	Our World in Data (OWiD)	Metric tons per capita
Gross Domestic Product	LGDP	World Bank	USD
Gross Domestic Product	LGDP2	World Bank	USD
Hydro Energy Consumption	LHYDRO	BP World Energy	Exajoules
Fuel Energy Consumption	LFUEL	BP World Energy	Exajoules
Total population	LTOPOP	World Bank	Number of people
Urban population	LURBAN	World Bank	Number of people

Source: World Bank (2023); BP World Energy (2023); Our World in Data (2023)

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume IX Issue V May 2025

Equation (1) may be rewritten as follows:

$$LCO2 = \alpha_0 + \alpha_1 LGDP_t + \alpha_2 LGDP2_t + \alpha_3 LHYDRO_t + \alpha_4 LFUEL_t + \alpha_5 LTOPOP_t + \alpha_6 LURBAN_t + \varepsilon_t \quad (2)$$

In Equation (2), LCO2 proxy as the indicator for sustainable environment condition, LGDP and LGDP2 proxy to the economy condition and income of the countries. The economy factor is importance variable as it will give evident for the Kuznets curve. This study is comparing 2 largest energy resources consume from renewable and non-renewable sources. The variable LHYDRO is used to measure the consumption of energy from renewable sources, while the variable LFUEL is used to measure the consumption of energy from non-renewable sources (fossil fuels). LTOPOP and LURBAN provide coverage for the population in Indonesia. Indonesia is known to have a crowded population, with the status of being the fourth largest population in the world. The country's urban areas, serving as its metropolitan cities, are crucial factors as many economic activities take place there. The model coefficients are α_1 to α_6, and t is identified as the time series data from 1980 to 2018. ε_t represents the error term in the model.

$$\Delta LCO2 = c_1 + \sum_{i=1}^{p} \alpha_{1i} \Delta LCO2_{t-i} + \sum_{i=0}^{q} \alpha_{2i} \Delta LGDP_{t-i} + \sum_{i=0}^{r} \alpha_{3i} \Delta LGDP2_{t-i} + \sum_{i=0}^{s} \alpha_{4i} \Delta LHYDRO_{t-i}$$
$$+ \sum_{i=0}^{k} \alpha_{5i} \Delta LFUEL_{t-i} + \sum_{i=0}^{l} \alpha_{6i} \Delta LTOPOP_{t-i} + \sum_{i=0}^{m} \alpha_{7i} \Delta LURBAN_{t-i} + \beta_1 LGDP_{t-1}$$
$$+ \beta_2 LGDP2_{t-1} + \beta_3 LHYDRO_{t-1} + \beta_4 LFUEL_{t-i} + \beta_5 LTOPOP_{t-i} + \beta_6 LURBAN + \varepsilon_t \quad (3)$$

Equation (3) is the ARDL model for the model in equation (2). According to Pesaran et al. (2001), Mohamad and Ab-Rahim (2024c) and Soh et al. (2025), the ARDL model is robust technique to clarify the short and long run relationship between the variables. Root test is importance step before enable this method and the F-test is require as the bound test to ensure there is long run cointegration. This study estimates the cointegration of economy (GDP, GDP2), the energy consumption from renewable (LHYDRO) and non-renewable (LFUEL), and Indonesia total population and urban population, respectively; (LTOPOP) and (LURBAN) toward the environment (CO_2).

FINDINGS

Table 2 shows the descriptive analysis and matric correlations of 42 annual observations from 1980 to 2021. There are seven variables, and two out of all the means are reported as negative. The data surface is normally distributed, as the gap between the maximum and minimum values is close to the median. Furthermore, the apparent value of the skewness test for all variables is between 1 and -1, and the kurtosis test also shows a range of less than 3, indicating that the data were normally distributed (Orcan, 2020). The matrix correlations are used to identify the correlation between these variables from the surface. When compared to other variables, hydro energy (-0.573) is the variable that correlates most closely with CO_2 emissions, and it has a negative value. However, the value is relatively low. Most variables, in fact, exhibit a low correlation with CO_2 emissions. The other variables that are closely related to the GDP are hydro energy (0.767), fuel energy (0.889), total population (0.940), and urban area population (0.927).

Table 2. Descriptive analysis and matrix correlations

	LCO2	LGDP	LGDP2	LHYDRO	LFUEL	LTOPOP	LURBAN
Mean	-1.335	26.279	691.513	-2.496	0.653	19.167	18.230
Med.	-1.321	26.065	679.374	-2.303	0.846	19.189	18.331
Max.	-1.152	27.802	772.934	-1.470	1.166	19.428	18.871

Min.	-1.546	25.007	625.331	-4.605	-0.198	18.814	17.305
Std. Dev.	0.086	0.980	51.779	0.814	0.448	0.182	0.475
Skew.	-0.100	0.276	0.302	-1.332	-0.593	-0.304	-0.410
Kurtosis	2.994	1.551	1.558	4.196	1.848	1.920	1.916
Jarque-Bera	0.070	4.211	4.277	14.929	4.787	2.685	3.229
Prob.	0.966	0.122	0.118	0.001	0.091	0.261	0.199
Obs.	42	42	42	42	42	42	42
Variable	LCO2	LGDP	LGDP2	LHYDRO	LFUEL	LTOPOP	LURBAN
LCO2	1.000	-0.133	-0.126	-0.573	-0.489	-0.412	-0.444
LGDP	-0.133	1.000	1.000	0.767	0.889	0.940	0.927
LGDP2	-0.126	1.000	1.000	0.764	0.884	0.938	0.924
LHYDRO	-0.573	0.767	0.764	1.000	0.880	0.907	0.910
LFUEL	-0.489	0.889	0.884	0.880	1.000	0.973	0.982
LTOPOP	-0.412	0.940	0.938	0.907	0.973	1.000	0.999
LURBAN	-0.444	0.927	0.924	0.910	0.982	0.999	1.000

Source: Calculation by author’s

The initial task is to ascertain the optimal lag time for each variable. The session border controller (SBC) criteria used to select the sequence for the ideal lag-length. Table 3, therefore, displays the outcomes of the analysis on unit roots. For the Augmented Dickey Fuller (ADF) test, it is revealed that all variables are non-stationary at levels. However, the first difference exhibits significant results at a 1% level for most variables, with the exception of Indonesia’s total population and the population in the urban area. However, using the Phillips–Perron (PP) unit roots test indicates all variables are not significant at levels then, after the first different, the study able to gain all variables are stationary at 1% significance. Therefore, this clarifies that the variables are considered suitable for applying the Autoregressive distributed lag method of cointegration (Mohamad et al., 2023, Mohamad et al., 2024b)

Table 3. Unit roots test

Variables	PP		ADF	
	I (0)	I (1)	I (0)	I (1)
LCO2	-2.457	-7.354***	-2.597	-6.236***
LGDP	-2.291	-5.732***	-2.273	-6.380***
LGDP2	-2.239	-5.655***	-2.221	-6.313***
LHYDRO	-2.690	-7.158***	-2.732	-5.427***

LFUEL	0.343	-4.413***	0.330	-5.392***
LTOPOP	-2.932	-5.493***	1.700	0.334
LURBAN	-0.116	-2.923***	-1.234	-0.061

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

Source: Calculation by author's

Table 4. Upper bound test

Model (Max lag; 3,3)	Lag order	F-stat	Outcome
LCO2= f (LGDP, LGDP2, LHYDRO, LFUEL, LTOPOP, LURBAN)	(2, 2, 3, 2, 2, 1, 3)	5.544 ***	Cointegration
F-Statistics (Critical values)	Lower I (0)	Upper (1)	Status
10%	2.218	3.314	Cointegration
5%	2.618	3.863	Cointegration
1%	3.505	5.121	Cointegration

Source: Calculation by author's

Table 4 presents the results of the ARDL bound testing for cointegration (with a maximum lag of 3), with an F-test that is significant for the upper limit at the 1%, 5%, and 10% critical values. It is indicated that a significant long-term association exists between CO_2 emissions, fuel energy, and renewable energy consumption in Indonesia. The current study assesses the lag duration order of both economic prosperity and renewable energy consumption using the minimal value of SBC. Furthermore, after validating the evidence of a long-term relationship between renewable energy and fuel energy's impact on the environment, the next stage in the investigation is to use the ARDL technique to determine the beta value of short and long-run cointegration.

Table 5. ARDL short run

Variables	Coefficient	Std. Error	t-Stat
$\Delta LCO2_{(-1)}$	0.149	0.192	0.777
$\Delta LCO2_{(-2)}$	-0.415**	0.163	-2.550
ΔLGDP	1.522	2.392	0.636
$\Delta LGDP_{(-1)}$	-2.319	2.798	-0.829
$\Delta LGDP_{(-2)}$	8.389***	2.836	2.958
ΔLGDP2	-0.025	0.046	-0.553

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume IX Issue V May 2025

$\Delta LGDP2_{(-1)}$	0.043	0.054	0.795
$\Delta LGDP2_{(-2)}$	-0.163***	0.055	-2.961
$\Delta LGDP2_{(-3)}$	0.004**	0.002	2.463
ΔLHYDRO	-0.084	0.049	-1.718
$\Delta LHYDRO_{(-1)}$	-0.087	0.050	-1.731
$\Delta LHYDRO_{(-2)}$	0.073	0.043	1.711
ΔLFUEL	0.369*	0.193	1.912
$\Delta LFUEL_{(-1)}$	0.465**	0.214	2.176
$\Delta LFUEL_{(-2)}$	0.321	0.248	1.295
ΔLTOPOP	-62.783***	19.469	-3.225
$\Delta LTOPOP_{(-1)}$	80.498***	20.347	3.956
ΔLURBAN	-22.908***	7.752	-2.955
$\Delta LURBAN_{(-1)}$	26.811**	10.583	2.533
$\Delta LURBAN_{(-2)}$	-4.981	7.400	-0.673
$\Delta LURBAN_{(-3)}$	-7.699*	4.182	-1.841
Adjusted R-squared	0.821	-	-
F-statistic	9.284***	-	-

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

Source: Calculation by author's

The table 5 contains the results of the ARDL short run with an interesting relationship among the variables. The cointegration of GDP, GDP2, energy from hydro and fossil fuel, and the urban and total population of Indonesia toward CO_2 emissions finds that CO_2 is significant with a negative value. This also shows the environment is having a positive reaction, and the Kuznets theory gives more evidence. As the Kuznets curve in the short run resulted in an inverted U-shaped, the GDP was reported as significantly positive (8.389), while the GDP2 also indicated a significant value, however, was negative. The fuel energy (0.369) is significant at 10%, and (0.465) is significant at 5%, with both positive signs indicating that the consumption of fossil fuels will increase environmental degradation. The urban and total population in Indonesia show two signs of positive and negative values, indicating there can be positive and negative impacts on the environment.

Table 6. ARDL long run

Variables	Coefficient	Std. Error	t-Stat
LGDP	5.9971***	1.9597	3.0602
LGDP2	-0.1114***	0.0367	-3.0326

LHYDRO	-0.0775	0.0464	-1.6684
LFUEL	0.9124***	0.2409	3.7882
LTOPOP	13.9939***	3.6967	3.7856
LURBAN	-6.9331***	1.4866	-4.6638
C	-223.7366***	58.3975	-3.8313

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

Source: Calculation by author's

EC = LCO2 - (5.9971*LGDP - 0.1114*LGDP2 - 0.0775*LHYDRO + 0.9124*LFUEL + 13.9939*LTOPOP - 6.9331*LURBAN - 223.7366)

The ARDL long run in table 6 indicates that most of the variables are significant towards CO_2 emissions, except for hydro energy. The GDP, which has a positive value of 5.9971, is significant. This implies that an increase in GDP in Indonesia will also result in a higher generation of CO_2 emissions. The GDP2 had a significant and negative value of -0.1113. Therefore, it can be inferred from GDP2 that an increase in GDP2 will lead to a reduction in CO_2 emissions. It is evident that Indonesia exhibits an Inverted U-curve in Kuznets theory. The same result has also been found in the previous study by Sugaiwan and Managi (2016). The relationship between CO_2 and economic growth in Indonesia has been observed to have an inverted U-shape between the years 1971 and 2010.

The fuel energy is also significant with a positive value (0.9124), and it has been proven that the fuel energy is harmful to the environment. The fuel energy releases more carbon in the atmosphere, thus increasing CO_2 emissions. The urban population and total population also indicate significance, however with different signs. As the total population (13.9939) shows, the increasing total population in Indonesia will eventually increase CO_2 emissions. On the other hand, the increasing population in urban areas has a different effect, as the CO_2 emissions are -6.9331, meaning that urban areas are more aware of environmental degradation. Thus, the urban population is more inclined toward sustainable energy compared to the rural population in Indonesia. This finding is similar to empirical study by Sasana (2017), that proven that Indonesia significantly increases it CO_2 emissions from the growing population and use of fossil fuels.

Table 7. Diagnostic test

Test	F-stat	Result
Jarque-Bera	0.655 (0.721)	Normal distribute
Serial Correlation LM Test	3.745 (0.05)	No serial correlation problem
Heteroskedasticity Test: Breusch-Pagan-Godfrey Harvey Glejser	 1.170 (0.371) 0.985 (0.516) 1.093 (0.427)	No heteroskedasticity problem

Source: Calculation by author's

The diagnostic test (table 7) examines whether the model is free from bias. The data was normally distributed, and the F-test is 0.655 (0.721) for the Jarque-Bera, which is bigger than the 0.05 error term. There is no serial correlation issue with the value of 3.745 (0.05) for the LM test. Moreover, the heteroskedasticity test using Breush-Pagan-Godfrey (0.371), Harvey (0.516), and Glejser (0.427) also indicates a value greater than 0.05; therefore, no heteroskedasticity problem was detected. The model is also perfectly stable with both tests in figure 2a: CUSUM, and figure 2b: CUSUM Square, which are within the 5% significant line. This concludes that the model is robust and perfectly stable to clarify the result for the cointegration of CO_2 emissions with fuel energy and renewable energy consumption in Indonesia.

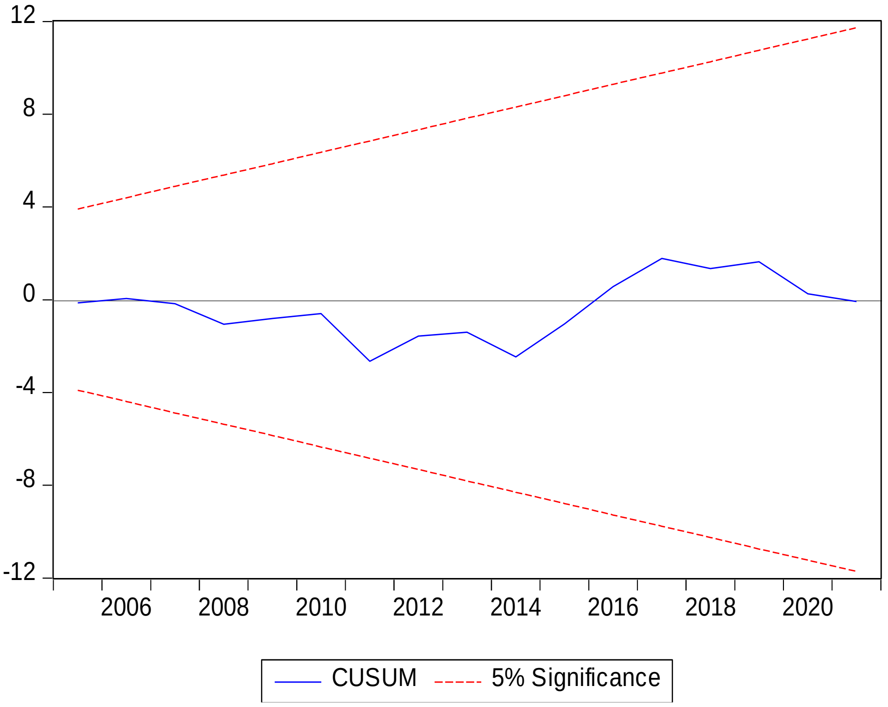

Figure 2a. CUSUM

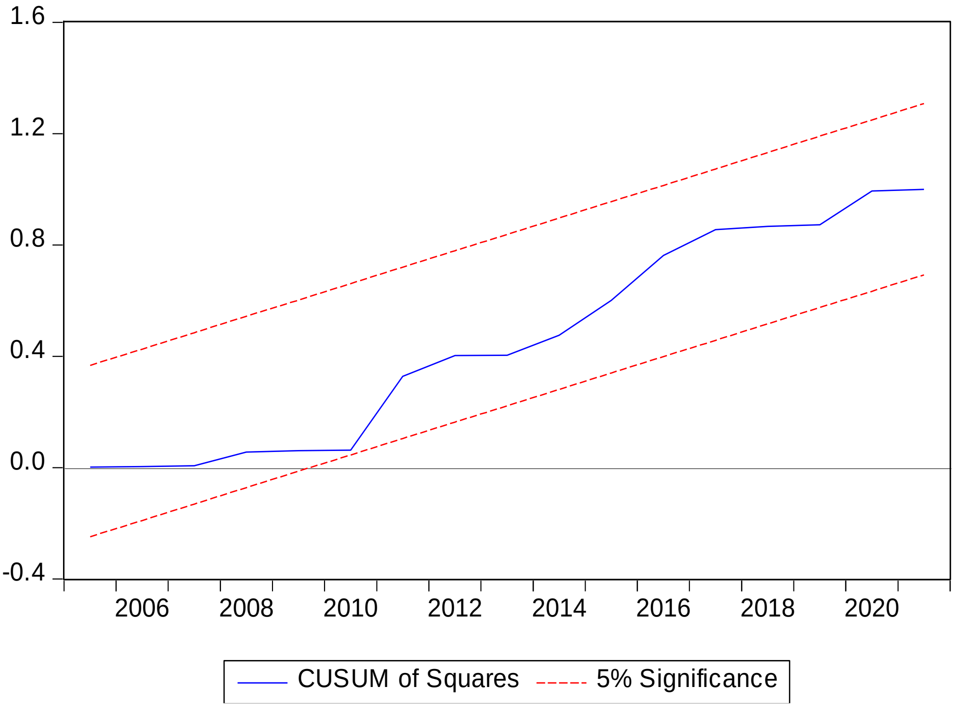

Figure 2b. CUSUM Square

Policy Toward the Transition on Renewable Energy

To address the issues of global warming and its related consequences, particularly climate change, it is necessary for the world to collaborate. There is a need for an increase and improvement in awareness and better environmental stewardship from the business sector. Additionally, strong political commitment from countries is necessary to introduce and enforce environmental regulations in order to curb CO_2 emissions. There are two methods for addressing climate change: mitigation, which involves prevention, and adaptation, which involves responding (Veal & Mouzas, 2010).

Although adaptation is acceptable but it is better to be more precaution by planning and implementing mitigation measures to reduce long term risks. According to Moriarty and Honnery (2014) the main mitigation method so far has been the promotion of alternatives energy and consideration of non-energy-based techniques for curbing climate change. Other initiatives include energy efficiency and conservation, forest and soil management and CO_2 capture and storage (Veal & Mouzas, 2010).

The 1991 Kyoto protocol is a legally binding national respond to climate change (Veal and Mouzas, 2010) that marked a very important achievement in global agreement to reduce GHGs emissions. This was initially done by establishing three flexible mechanisms for international cooperation, which were International Emissions Trading, Clean Development Mechanism (CDM) and Joint Implementation (JI) (Nai et al., 2017). Kyoto Protocol was effective in 2005, for the industrialised developed countries to reduce GHGs emission (Olson, 2009) with the first commitment period expired in 2012 (Jui et al., 2017).

Global issues, mechanisms and agreement were discussed and negotiated in the Conference of the Parties (COP). In the COP13 under the Bali Action Plan, a significance milestone was the introduction of the concept Nationally Appropriate Mitigation Actions (NAMAs), which stated that the developing countries should bore the responsibility of mitigation rather than of commitment and obligation, which was to be supported via technology, financing and capacity building (Jui et al., 2017). In the COP25, which was held in Madrid, both the developed and developing countries were to come out with their target reduction, known as the Intended Nationally Determined Contributions (INDCs) (Jui et al., 2017).

The second legally binding document after Kyoto Protocol is the Paris Agreement, ratified by 196 countries in the COP26 (Han et al., 2022) that are supposed to observe the INCs mechanism, and using new emission reduction models to combat climate change (Yang et al., 2021). The main goals of the Paris Agreement are to limit global warming to 1.5°C, GHGs emission increase is limited to peak before 2025 and targeted to decline 43% by 2030 (UNCC, 2023). Some positive implications of the Paris Agreement include business sectors are now more readily opting for zero-carbon solutions, especially in the power and transport sectors and it is expected that by 2030, these solutions will be adopted by sectors representing 70% of global emissions (UNCC, 2023). The next COP28 is scheduled to be at the end of December 2023, with the main concern to monitor stocktaking of data of each country INCs in their efforts to reduce CO_2 emission.

This issue is not exclusive to Indonesia only, however, goes beyond only the use of energy by just a country. Salman et al. (2019) make it clear that many other countries also play a vital role in curbing carbon emissions while promoting economic growth. Moreover, Karakurt et al. (2023) demonstrates that other developing economies, such as those in BRICS (Brazil, Russia, India, China, and South Africa) and MINT (Mexico, Indonesia, Nigeria, and Turkey), face a precipitous increase in fossil fuel consumption and CO_2 emissions by 2045. Therefore, the world needs innovative a smart policy, new technologies, and a swift transition toward the renewable energy sources to break the link between economic growth and environmental devastation.

The transition towards renewable energy in Indonesia has garnered considerable scholarly attention, revealing a complex landscape shaped by economic, environmental, and socio-political factors. Adrian et al. (2023) argues that despite its abundant renewable energy potential, Indonesia's energy sector remains dominated by fossil fuels due to policy roadblocks and lack of financial support. The need for increased investment and government commitment for this transition is echoed by several other researchers. Reyseliani and Purwanto (2021), highlight the technical challenges of this transition, forecasting the need for substantial solar and nuclear installations and increased electricity production costs. Erdiwansyah et al. (2021) study provides a more optimistic outlook, estimating significant economic growth due to renewable energy implementation and acknowledging supportive government policies.

Pambudi et al. (2023) advocate for robust policies and private sector involvement, while Rahman et al. (2021) urges for dynamic modeling and public acceptance studies to inform policy planning. Setyowati (2021) further calls for inclusive energy policies, context-specific solutions, and reevaluation of private climate finance to rectify current energy injustices. The role of renewable energy in rural electrification and poverty reduction is a recurring theme in the literature. Syahputra and Soesanti (2021) exemplify the potential of renewable energy in rural electricity provision, while, Wirawan and Gultom (2021) assert there is a positive effects of renewable village grids on poverty reduction and economic growth in remote areas. The interplay of renewable energy and sustainable urban development is explored by Surya et al. (2021) in two separate studies, emphasizing community empowerment, renewable energy utilization, and institutional capacity building in urban slum management and city service structures. Maulidia et al. (2019) underscore the broader policy context, identifying fossil fuel subsidies and a monopolistic energy landscape as key impediments to Indonesia's energy transition.

In terms of sustainability planning, Al Hasibi (2021) study presents an optimization model that balances cost and sustainability, finding a scenario with the highest sustainability index despite its higher cost. The integration of renewable energy in public institutions is explored by Riayatsyah et al. (2022), showing the feasibility of such a transition even in a low electricity rate country. Finally, the positive impacts of renewable energy production, energy efficiency, and green finance on sustainable economic development are affirmed by Tiawon and Miar (2023), advocate for comprehensive energy efficiency policies and green finance infrastructure. Overall, the significant potential and multi-faceted challenges in Indonesia's transition towards renewable energy. It suggests that a successful transition necessitates not only technological adaptations and investment but also policy reforms, stakeholder collaboration, and a keen consideration for energy justice and sustainable development.

A successful renewable energy transition also hinges critically on the alignment of infrastructure development, sustained investment, and unwavering political will. Adequate infrastructure is the backbone for integrating renewable sources into national grids, particularly in archipelagic nations like Indonesia, where geographic dispersion poses significant transmission and distribution challenges (Yuwono et al., 2025). According to Hassan et al. (2024), large-scale investments are required not only in generation technologies—such as solar farms, wind turbines, and hydropower plants—but also in smart grid systems, energy storage, and grid interconnectivity to ensure stability and scalability. However, these investments are often hindered by regulatory uncertainties, perceived market risks, and limited financial incentives. Thus, a clear, long-term regulatory framework is essential to attract both domestic and foreign investors. Political commitment plays a pivotal role in orchestrating this transition; governments must demonstrate leadership through consistent policies, phasing out fossil fuel subsidies, prioritizing renewable energy in national development plans, and facilitating public-private partnerships (Aditya et al., 2025). Moreover, cross-sectoral coordination and inclusive stakeholder engagement are necessary to ensure that the infrastructure and investments are aligned with national goals on decarbonization and social equity. Without strong political resolve and strategic investment in energy infrastructure, the transition to renewable energy will remain slow and fragmented, undermining both environmental targets and economic resilience.

CONCLUSION

In light of global concerns about climate change and the diminishing supply of fossil fuels, Indonesia is strategically positioning itself as a key player in the global shift towards cleaner and more sustainable energy alternatives. In recent years, Indonesia has made significant strides towards diversifying its sustainable energy status. This study underscores the critical interplay between economic growth, energy consumption patterns, and environmental sustainability in Indonesia. Through the application of the ARDL model using time-series data from 1980 to 2021, the analysis provides compelling evidence that fuel energy consumption significantly contributes to rising CO_2 emissions, while hydro energy—despite its current underutilization—offers a cleaner alternative with negative environmental impacts. The confirmation of the Environmental Kuznets Curve (EKC) in both short and long runs indicates that while economic growth initially exacerbates environmental degradation, it eventually leads to improved environmental outcomes as income rises and cleaner technologies are adopted.

The practical implications of these findings are manifold. Firstly, Indonesia must continue and accelerate its transition to renewable energy, especially by scaling up investments in hydro, solar, and other clean technologies.

The government should prioritize the development of renewable energy infrastructure, phase out fossil fuel subsidies, and create enabling policies to attract private and foreign investment. Secondly, targeted urban policies and education initiatives can leverage the environmentally-conscious behaviour seen in urban populations to influence broader national energy behaviour. Political will remains crucial; sustained and coordinated efforts are needed across national, regional, and local levels to implement consistent regulatory frameworks, enforce emissions targets, and strengthen public-private partnerships.

Future research should expand beyond hydroelectricity to assess the contributions of other renewable sources such as solar, wind, and geothermal energy. Moreover, spatially disaggregated studies focusing on Indonesia's many remote and island regions are essential to understand localized challenges and potentials for green energy adoption. Finally, integrating qualitative aspects—such as public perception, behavioural change, and institutional readiness—will enrich our understanding of the social dynamics behind energy transitions. A multidisciplinary approach combining economics, engineering, political science, and social psychology will be crucial in crafting holistic and actionable solutions for a low-carbon future in Indonesia.

ACKNOWLEDGEMENT

This research is funded by University College of Technology Sarawak, grant number UTS/RESEARCH/3/2024/12

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