The Impact of Economic Factors on Changing Carbon Emission Landscape in ASEAN With ARDL Approach

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Abstract

This study aims to analyze the factors influencing carbon emissions in the member countries of the Association of Southeast Asian Nations (ASEAN). The data used in this study covers the period from 1990 to 2021, utilizing the Autoregressive Distributed Lag (ARDL) analysis method. All independent variables show a significant impact on carbon emissions in both the short and long term. This research provides evidence that factors such as urbanization, foreign direct investment, population, and economic growth significantly contribute to the increase in carbon emissions in ASEAN countries. The findings also validate the Environmental Kuznets Curve hypothesis for carbon emissions in ASEAN countries. In other words, economic growth leads to a reduction in carbon emissions. The ASEAN region has experienced substantial economic growth over the past few decades. However, carbon dioxide (CO2) remains a socio-economic issue in the ASEAN region. The results of this study can be highly beneficial for policymakers in the region regarding sustainability and economic development.

Keywords: carbon emissions, urbanization, foreign direct investment, population, economic growth, ASEAN

JEL : O40, O44, Q50

DOI : 10.24002/kinerja.v28i2.8583

Received : 01/19/2024 Reviewed: 07/19/2024 Final Version: 02/09/2024

1. INTRODUCTION

One of the biggest challenges in achieving the SDGs by 2030 is the issue of deteriorating environmental quality due to economic activities (Zafar et al., 2019). Both developed and developing countries are facing significant challenges in accelerating economic growth while still considering the protection of environmental quality (Hassan et al., 2019). Environmental development encompasses various aspects, including economic, technological, social, and cultural dimensions. This is closely related to the development of various sectors such as industry, agriculture, forestry, mining and energy, transportation, education, health, tourism, trade and foreign affairs, technology, business, and regional development. Economic development often coincides with a decline in environmental resilience and functionality. Development that is overly oriented toward pursuing growth frequently neglects environmental management aspects (Bieth, 2021).

The ASEAN (Association of Southeast Asian Nations) region is one of the most dynamic and rapidly growing economic areas in the world (Silitonga et al., 2017). The energy mix in this region has historically been dominated by fossil fuels, such as coal in Indonesia, the Philippines, and Malaysia, as well as oil and gas in Vietnam, Thailand, and Singapore (Marquardt, 2016). Approximately 90 percent of the commercial energy needs in ASEAN are met by fossil fuel combustion. This raises concerns that the rapid growth experienced by these countries, driven by high energy consumption, could potentially contribute to greenhouse gas emissions and the resulting climate change (Munir et al., 2020). This dominance has contributed to providing cheap and reliable energy in these countries, thereby supporting their socio-economic prosperity (Ismail et al., 2013). Nevertheless, this has turned the energy sector into the leading source of greenhouse gas emissions in the region, making it a key contributor to global warming, one of the most pressing issues facing humanity (Mofijur et al., 2019).

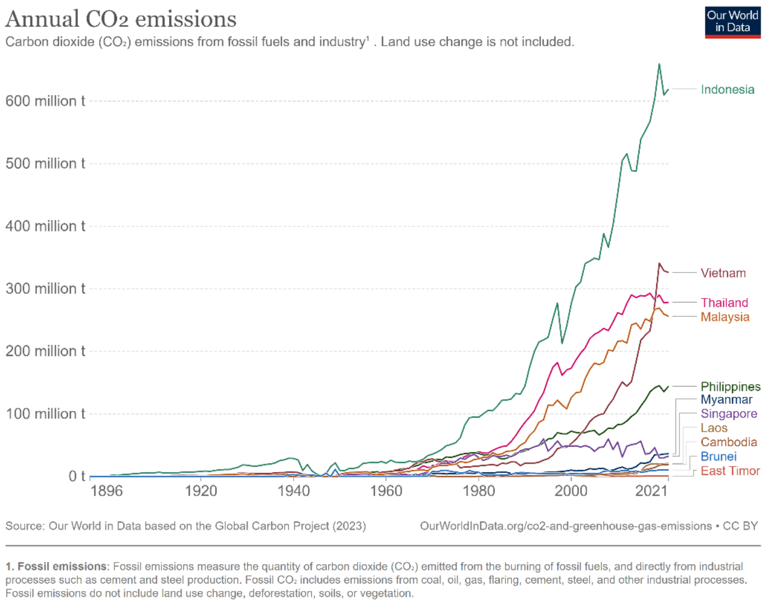

Figure 1. The Ratio of The ASEAN Total CO2 Emissions.

The National Oceanic and Atmospheric Administration (NOAA) released the Global Climate Report in 2020, stating that the combined land and sea temperatures have increased by an average of about 0.08 degrees per decade since 1880 (Lisaba Jr & Lopez, 2021). Concerns about worsening global environmental quality have become pronounced, as clearly illustrated by the increasing trend in atmospheric carbon emissions, as shown in Figure 1. CO2 is identified as a major contributor to global warming (Lisaba Jr & Lopez, 2021). Given the clear correlation between carbon dioxide emissions and global warming, it is recommended to seek solutions involving the mitigation of greenhouse gas emissions into the atmosphere. The World Health Organization (WHO) states that global warming will significantly impact human health and the environment (World Health Organization, 2021). WHO reports estimate that approximately 250,000 people will die between 2030 and 2050 due to climate change. Of particular concern is that the WHO predicts that regions with weak health infrastructure, which are primarily found in developing countries, will be the least equipped to cope with climate change. Therefore, this highlights the need to find alternative solutions to reduce carbon dioxide emissions.

Global warming is correlated with increased frequency and intensity of natural disasters, such as typhoons, droughts, and floods. It should be noted that Southeast Asia is located to the west of the Pacific Ocean, where about one-third of the world's annual tropical cyclones are formed (Lisaba Jr & Lopez, 2021). Given that the majority of its member countries are archipelagic, the impacts of climate change will become increasingly evident and damaging if preventive measures are not taken promptly.

Southeast Asia contains many impoverished regions, with most countries heavily reliant on agriculture. Additionally, the region depends on forests and natural resources. Furthermore, it is argued that climate change negatively impacts areas reliant on agriculture, as global warming leads to reduced rainfall and rising sea levels, increasing by approximately one to three millimeters (Nunti et al., 2020). Facing the threat of rapidly increasing CO2 emissions, Southeast Asian countries are taking measures to protect the environment. The Association of Southeast Asian Nations (ASEAN) has revised its environmental protection policies in recent years. For instance, in 2007, ASEAN leaders adopted the Cebu Declaration on Energy Security. This declaration primarily encourages member states to enhance energy efficiency, promote the use of renewable energy, and adopt technologies that reduce CO2 emissions from coal burning (Setyadharma et al., 2021).

Southeast Asia has highly impoverished regions, and many countries in the area heavily rely on agriculture. Additionally, the region depends on forests and natural resources. It is further noted that climate change adversely affects areas dependent on agriculture, as global warming leads to reduced rainfall and a sea level rise of approximately one to three millimeters (Nunti et al., 2020). Faced with the threat of rapidly accumulating CO2 emissions, Southeast Asian countries are working to protect the environment. The Association of Southeast Asian Nations (ASEAN) has updated its policy framework to safeguard the environment in recent years. For example, in 2007, ASEAN leaders agreed to adopt the Cebu Declaration on Energy Security. The Cebu Declaration primarily encourages countries to focus more on energy efficiency, use renewable energy sources, and adopt technologies that reduce CO2 emissions associated with coal combustion (Setyadharma et al., 2021).

Given that Southeast Asia is highly vulnerable to various natural disasters, it is important to note that ASEAN countries have already begun taking preventive measures. They are not only collaborating on various programs but also formulating policies to mitigate the impacts of climate change. These policies involve carbon dioxide emission mitigation to reduce risks to life and property. According to ASEAN, several member countries have voluntarily pledged CO2 mitigation targets (ASEAN, 2021). Many ASEAN countries have made remarkable efforts to address these challenges. Various policies aimed at the adoption and use of renewable energy have been implemented, influenced not only by the Paris Agreement but also by national energy consumption plans.

The ASEAN Energy Outlook Fifth Report indicates that ASEAN member countries have made some progress in adopting renewable energy targets. For instance, Indonesia has developed and implemented plans to increase new and renewable energy to 23 percent of the total primary energy supply (TPES) by 2025 and around 30 percent by 2050, with the goal of reducing greenhouse gas (GHG) emissions by under 30 percent by 2020 compared to a business-as-usual scenario. Malaysia has set a target to increase renewable electricity supply capacity to approximately 8 percent of total installed capacity by 2020 and reduce GHG emission intensity relative to GDP by 35 percent by 2030, compared to 2005 levels. In its national renewable energy roadmap program through 2030, the Philippines has set targets to multiply the installed capacity of renewable energy sources by 2030 compared to 2010 levels, alongside controlling and stabilizing GHG emissions to less than 16 percent of business-as-usual levels. Thailand has more ambitious goals to increase renewable energy to 30 percent of total energy use by 2036, including in power generation, heating, and transportation fuel consumption. Expanding the use of renewable energy to rebalance the energy mix will significantly depend on resource availability, energy resilience, and a country's environmental targets (Munir et al., 2020).

Many factors influence environmental degradation, one of which is urbanization. Urbanization increases CO2 emissions, as research by Li et al. (2021) indicates that the migration of people to urban centers leads to industrialization, business expansion, and the construction of infrastructure such as roads, bridges, hospitals, and markets, all of which heavily rely on dirty energy consumption, thereby intensifying CO2 emissions in a country. The increase in urban population, along with greater energy consumption and the use of natural resources, results in higher CO2 emissions. Cities around the world account for more than two-thirds of global energy use, producing 70% of energy-related carbon dioxide emissions (Pata, 2018). However, previous research has found differing results, suggesting that urbanization does not impact carbon emissions. These studies argue that urbanization raises public awareness about environmental issues and the need to manage CO2 emissions, thereby helping to maintain emission levels (Adebayo et al., 2021; Jermsittiparsert, 2021).

Another factor that can increase carbon emissions is Foreign Direct Investment (FDI). While FDI can boost economic growth in the recipient country, it can also positively correlate with environmental pollution, especially in countries with polluting industries. Research by Essandoh et al. (2020), Khan & Ahmad (2021), and Opoku & Boachie (2020) found that FDI increases carbon emissions by promoting the transfer of high-emission production units from developed to developing countries. Additionally, investments in industries reliant on fossil fuels will likely raise carbon emissions. Conversely, studies by Ekwueme et al. (2021), Odugbesan & Adebayo (2020), and Salahuddin et al. (2018) indicate that FDI can also enhance environmental integrity. Investments in the energy sector can facilitate the introduction of the latest and cleaner technologies, such as solar panels or wind turbines, which can reduce CO2 emissions.

Increasing population leads to higher demand for oil, gas, coal, and other fuels that are extracted from below the Earth's surface. When burned, these fuels release significant amounts of carbon dioxide into the atmosphere, trapping warm air like a greenhouse (Lawal, 2019). Shi (2003) found a direct relationship between population changes and carbon dioxide emissions in 93 countries over the period 1975-1996. Similarly, research by Cole & Neumayer (2004) identified a positive correlation between CO2 emissions and both population and urbanization levels. Engleman (1994) plotted long-term trends in global industrial carbon dioxide emissions and population, finding that both emissions and population have grown at similar rates since 1970.

However, there is also evidence of a negative relationship between population and carbon emissions. This can be explained by the fact that as the number of people increases, the per capita emissions allocated to each individual may decrease. Additionally, previous studies have found that human activities negatively impact the rate of growth in per capita CO2 emissions, as densely populated areas have greater access to public transportation and other services. Moreover, higher demands for low-pollution environments and sustainable lifestyles can facilitate the reduction of CO2 emissions (Ahmed et al., 2017; Flamarz Al-Arkawazi, 2018).

The relationship between economic growth and carbon emissions is reciprocal, meaning that high economic growth can lead to increased resource use and production, which ultimately results in higher carbon emissions. These high emissions can exacerbate environmental problems, such as climate change, which in turn can affect economic growth (Dietz et al., 2007). Research by MikCayilov et al. (2018), Schröder & Storm (2020), and Sheraz et al. (2022) have found that economic growth is a key determinant of carbon emissions, as countries focus on enhancing economic performance, which drives increased production activities without considering the environmental impact. Conversely, Dong et al. (2020) found a negative relationship, indicating that factors such as investment in clean energy, strict environmental policies, and increased public awareness of environmental issues can help reduce carbon emissions. Shahbaz & Sinha (2019) explained that when the economy grows beyond a certain level, it tends to pursue technological advancements that can lead to pollution control.

This study has three main contributions. First, it aims to clarify previous findings where results have been inconsistent. Second, the panel ARDL method is relevant compared to other dynamic panel methods because it provides more consistent estimates and comprehensive results. Third, studying environmental factors is crucial as the role and existence of the environment are closely linked to economic activities.

2. LITERATURE REVIEW

2.1. Urbanization

Economic growth in several countries, particularly developing ones, accelerates the rate of urbanization (Odugbesan & Rjoub, 2020). Numerous studies have identified a significant relationship between urbanization, energy consumption, and environmental pollution (Behera & Dash, 2017). These studies argue that urban areas account for about 75% of global energy consumption and 60% of carbon emissions. Additionally, some analyses suggest that urbanization is a critical determinant of carbon emissions (Ali et al., 2016). A study focusing on China found that urbanization has a significant effect on CO2 emissions, with residential consumption being a major contributor (Yan et al., 2023). Other global analyses highlight that urban CO2 emissions are rising worldwide, with varying contributors based on development levels, and urban per capita emission trends generally exceed national averages (Luqman et al., 2023). Furthermore, a study on sub-Saharan Africa revealed a feedback relationship between urbanization and carbon emissions, emphasizing the importance of sustainable energy sources and waste recycling to improve environmental quality (Afriye et al., 2022). Therefore, these studies demonstrate that urbanization indeed impacts carbon emissions, with implications varying based on geographical location, economic characteristics, and policy interventions.

2.2. Foreign Direct Investment

Foreign Direct Investment (FDI) can contribute to environmental damage. The theory regarding the relationship between FDI and environmental degradation is known as the Pollution Haven Hypothesis (PHH). According to the Pollution Haven Hypothesis, FDI can improve environmental quality by transferring environmentally friendly technologies to developing countries (Birdsall & Wheeler, 1993). Copeland & Taylor (1994) argue that firms from developed countries seek to establish factories or offices in developing countries due to lower labor and resource costs. Developing countries often have less stringent environmental regulations, which further reduces production costs, especially for pollution-intensive industries (Christensen et al., 1996). Studies indicate that FDI can lead to increased carbon emissions in host countries, as foreign companies often use older and less environmentally friendly technologies. However, other research suggests that foreign direct investment can also introduce new and more environmentally friendly technologies to host countries (Frankel & Romer, 1999).

Research by Huang et al. (2022) indicates that Foreign Direct Investment (FDI) has a significant impact on carbon emissions in host countries, although the effect depends on the type of investment activity and the industrial structure of the host country. Abdouli & Hammami (2017) concluded that foreign investment has significantly increased the carbon footprint in MENA countries, supporting the Pollution Haven Hypothesis. Conversely, Mahadevan & Sun (2020) found that FDI contributes to a reduction in carbon emissions in host countries by decreasing fossil fuel use and introducing more environmentally friendly technologies. Research by Omri *et al*. (2014) and Joshua *et al*. (2020) suggests that foreign investment significantly contributes to enhancing ecological integrity and sustainability. Additionally, stringent government policies related to environmental protection and energy efficiency can help mitigate the carbon emissions associated with FDI (Wang *et al., 2019).*

The conclusion drawn from the existing literature is that the relationship between Foreign Direct Investment and carbon emissions is highly complex and depends on various factors, such as the type of industry, technology, environmental regulations, and government policies. Therefore, further research is needed to better understand this relationship.

2.3. Population

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The conclusion drawn from the existing literature is that the relationship between FDI and carbon emissions is highly complex and dependent on various factors, such as industry type, technology type, environmental regulations, and government policies. Therefore, further research is needed to better understand this relationship.

2.4. Economic Growth

The Feedback Hypothesis proposed by Dietz *et al*. (2007) explains the bidirectional relationship between economic growth and carbon emissions. This theory suggests that high economic growth can exacerbate environmental problems, thereby triggering efforts to reduce carbon emissions. High economic growth can lead to increased resource use and production, ultimately resulting in higher carbon emissions. These elevated carbon emissions can, in turn, worsen environmental issues such as climate change, which may subsequently impact economic growth (Siregar, 2023). Halliru *et al*. (2020) found no empirical evidence supporting the Kuznets Hypothesis concerning the relationship between economic growth and carbon emissions in Africa. The study discovered that economic growth has a significant positive effect on carbon emissions on the continent. Similarly, Sheraz *et al*. (2022) found that economic growth significantly impacts CO2 emissions in India due to the country's status as a developing nation with high energy demand and reliance on fossil fuels.

Conversely, Zhang (2021) found a significant negative relationship between economic growth and carbon emissions in China during the period from 2005 to 2017. This result suggests that China can achieve sustainable economic growth without increasing carbon emissions. In line with this, Dong *et al*. (2020) also found a significant negative relationship between economic growth and carbon emissions in China from 1990 to 2015. The study identified that factors such as investments in clean energy, stringent environmental policies, and increasing public awareness of environmental issues contribute to reducing carbon emissions in China. Shahbaz & Sinha (2019) explain in their research that when an economy grows beyond a certain level, the country will strive for technological advancements, which will lead to pollution control.

3. METHODOLOGY

The research focuses on ASEAN countries with a study period from 1990 to 2022. The data for this study is obtained from official publications of the World Bank. The population includes 11 ASEAN countries: Indonesia, Malaysia, Singapore, the Philippines, Thailand, Brunei Darussalam, Vietnam, Laos, Myanmar, Cambodia, and Timor Leste. For this study, the sample consists of countries with complete data. Consequently, the sample for this research includes 8 ASEAN countries: Indonesia, Malaysia, the Philippines, Thailand, Brunei Darussalam, Vietnam, Laos, and Myanmar. The sampling technique used in this study falls under non-probability sampling.

This study employs the Autoregressive Distributed Lag (ARDL) bound-test method for time series data analysis to identify the presence of cointegration or long-term relationships among the research variables. The ARDL bound test, developed by Pesaran et al. (2001), offers several advantages compared to other cointegration methods. These advantages include (i) applicability to time series data with stationarity levels I(0), I(1), or a mix of both, (ii) providing better results for small sample sizes, and (iii) offering simultaneous long-term and short-term estimates. To examine the stationarity level of the variables, the study uses the Augmented Dickey-Fuller test. This is intended to avoid biased and unreliable conclusions that might arise if structural breaks in the time series data are not considered (Enders, 2014; Gujarati & Porter, 2009).

The Pedroni test is used for cointegration testing among variables to identify whether there is a long-term equilibrium relationship between the variables in the model. If the variables are cointegrated, they share a common long-term trend, even though they may fluctuate in the short term. Cointegration is indicated when the p-value is less than alpha. The choice of panel ARDL is made because it provides both long-term and short-term estimates, as shown in equations 1 and 2, and cross-sectional coefficients for short-term ECT, which help address the research objectives.

Panel ARDL is a technique for examining each lag of variables that are either I(1) or I(0). The results from panel ARDL regression include test statistics that can be compared to two asymptotic critical values (Rusiadi & Subiantoro, 2014). Using the panel ARDL model, which assumes that the variables in this study are dynamic, is appropriate for this research.

$$CO2_t = \delta_{0i} + \sum_{i=1}^{n} \delta_{1i}\, CO2_{t-i} + \sum_{i=1}^{n} \delta_{2i}\, URB_{t-i} + \sum_{i=1}^{n} \delta_{3i}\, FDI_{t-i} + \sum_{i=1}^{n} \delta_{4i}\, POP_{t-i} + \sum_{i=1}^{n} \delta_{5i}\, GDP_{i,t-1} + \varepsilon t \quad (1)$$

$$\Delta CO2_t = \alpha_0 + \sum_{i=1}^{n} \alpha_{1i}\, \Delta CO2_{t-i} + \sum_{i=1}^{n} \alpha_{2i}\, \Delta URB_{t-i} + \sum_{i=1}^{n} \alpha_{3i}\, \Delta FDI_{t-i} + \sum_{i=1}^{n} \alpha_{4i}\, \Delta POP_{t-i} + \sum_{i=1}^{n} \alpha_{5i}\, \Delta GDP_{t-i} + \theta \mathrm{ECT}_{\,t-1} + \varepsilon t \quad (2)$$

The symbol Δ represents the difference operator, $\delta 1 - \delta 5$ are the long-term coefficients, $\alpha 1 - \alpha 5$ are the short-term coefficients, and $ECTt-1$ represents the extent of adjustment for short-term imbalances or the speed of adjustment to return to long-term equilibrium. The coefficient of $ECTt-1$ is expected to be negative and significant.

Next, Granger causality tests are conducted to identify causal relationships by determining whether changes in one variable cause changes in another and vice versa. Additionally, this test enhances the understanding of the dynamic mechanisms underlying the relationships between variables in the model. Causality tests also help validate the model by ensuring that the observed relationships are not the result of spurious correlation.

4. RESULT AND DISCUSSION

In the first section, the results of the stationarity and cointegration tests are presented. The second section provides the long-term estimates from the panel ARDL model. The final section presents the short-term estimates from the panel ARDL model, along with the coefficients of the error correction term.

Table 1. Unit Roots Test Results

Variable	Level & First Diff.	Intercept/Trend	Prob. LLC	Prob. PP	Decision
Carbon Emissions	Level	Intercept	0.0380	0.0001	I(1)
		Interc. & Trend	0.9461	0.0000	
	First Diff.	Intercept	0.1592	0.0000*	
		Interc. & Trend	0.8360	0.0000*	
Urbanization	Level	Intercept	0.0000*	0.0000	I(0)
		Interc. & Trend	0.0000*	0.9371	
	First Diff.	Intercept	0.9652	0.5391	
		Interc. & Trend	1.0000	0.0000	
Foreign direct investment	Level	Intercept	0.0045	0.0003*	I(0)
		Interc. & Trend	0.0784	0.0082*	
	First Diff.	Intercept	0.0000	0.0000	
		Interc. & Trend	0.0007	0.0000	

Population	Level	Intercept	0.4519	0.0000*	I(0)
		Interc. & Trend	0.0254	0.0000*	
	First Diff.	Intercept	0.1188	0.0247	
		Interc. & Trend	0.0280	0.0303	
GDP	Level	Intercept	0.0598	0.0000*	I(0)
		Interc. & Trend	0.1999	0.0000*	
	First Diff.	Interc. & Trend	0.0000	0.0000	
		Interc. & Trend	0.0000	0.0000	

Source: Secondary (processed) data (2023).

The stationarity test results based on Levin, Lin, and PP-Fisher, as shown in Table 1, indicate that Carbon Emissions are stationary at level I(1) or first difference, while Urbanization, Foreign Direct Investment, Population, and GDP are stationary at I(0) or level. This confirms that the use of the panel ARDL model is appropriate for this research.

Table 2. Pedroni Cointegration Test Results

	Statistics	**Prob.**	**Weighted Statistics**	**Prob.**
V-Statistic Panel	0.544342	0.2931	-1.701996	0.9556
rho-Statistics Panel	-5.162608	0.0000	-2.585935	0.0049
Panel PP-Statistic	-9.021373	0.0000	-5.886513	0.0000
Panel ADF-Statistic	-0.092361	0.4632	-1.803758	0.0356

Source: Secondary (processed) data (2023).

The cointegration test offers the benefit of determining whether the variables in this study maintain a stable long-term relationship. This study used the Pedroni cointegration test, which includes Dickey-Fuller (DF) and Augmented Dickey-Fuller (ADF) tests, to test for cointegration in panel data. The results of the cointegration test yield residuals obtained by regressing independent variables on the dependent variable. The results shown in Table 2 indicate panel cointegration for ASEAN countries over the period 1990-2021, with a probability value of 0.0356, which is less than the alpha level of 0.05. In conclusion, there is evidence of cointegration between carbon emissions and macroeconomic variables (urbanization, foreign direct investment, population, and economic growth) in ASEAN countries over the long term. This finding suggests a tendency for the variables to move in the same direction in the future. The optimal results obtained from the panel ARDL model, where the lags were determined as (3, 4, 4, 4, 4), were achieved using the Akaike Information Criteria (AIC) for lag selection.

Table 3. ARDL Models

Model	**LogL**	**AIC***	**BIC**	**HQ**	**Models**
12	**589.937.563**	**-3.803.014**	**-1.305.202**	**-2.794.775**	**ARDL(3, 4, 4, 4, 4)**
16	590.281.383	-3.734.655	-1.114.998	-2.677.234	ARDL(4, 4, 4, 4, 4)
8	568.665.656	-3.684.514	-1.308.546	-2.725.458	ARDL(2, 4, 4, 4, 4)
4	548.273.769	-3.573.874	-1.319.751	-2.664.400	ARDL(1, 4, 4, 4, 4)
9	509.720.297	-3.363.852	-1.353.217	-2.679.245	ARDL(3, 3, 4, 4, 4)
7	497.105.726	-3.331.071	-1.442.717	-2.569.974	ARDL(3, 3, 3, 3, 3)
15	496.292.987	-3.196.803	-1.663.743	-2.524.700	ARDL(4, 3, 3, 3, 3)
3	458.014.885	-3.172.964	-1.682.004	-2.303.124	ARDL(1, 2, 3, 3, 3)
14	456.489.969	-3.115.169	-1.637.476	-2.451.207	ARDL(2, 2, 2, 2, 2)

Model	LogL	AIC*	BIC	HQ	Models
11	455.896.990	-3.114.516	-1.631.287	-2.451.024	ARDL(2, 2, 2, 1, 2)
13	419.633.875	-2.885.407	-1.217.097	-2.094.397	ARDL(4, 1, 1, 1, 1)
10	429.265.124	-2.862.177	-1.407.456	-2.608.947	ARDL(4, 1, 1, 2, 2)
5	402.316.146	-3.056.394	-1.424.560	-2.658.526	ARDL(2, 1, 1, 1, 1)
2	388.443.479	-3.003.960	-2.211.970	-2.684.742	ARDL(1, 1, 1, 1, 1)
12	589.937.563	-3.803.014	-1.305.202	-2.794.775	ARDL(3, 4, 4, 4, 4)

Source: Secondary (processed) data (2023).

Table 4. Long-Term Estimation Results

Variable	Coefficient	Std. Error	t-Statistics	Prob.
URB	0.007934	0.001579	5.024999	**0.0000***
FDI	0.021476	0.001894	11.33833	**0.0000***
POP	2.156516	0.129193	16.69219	**0.0000***
GDP	-0.004888	0.001462	-3.342392	**0.0012***

Source: Secondary (processed) data (2023).

Table 4 presents the long-term estimation results relevant to this study. All variables have a significant impact on Carbon Emissions (CO2) in the long term, as indicated by p-values smaller than the alpha level of 0.05. The findings reveal the following: first, a 1% increase in urbanization results in a 0.007 increase in carbon emissions in the long term. Second, a 1% increase in foreign direct investment leads to a 0.021 increase in carbon emissions. Third, a 1% increase in population causes carbon emissions to rise by 2.156. Fourth, a 1% increase in economic growth results in a decrease in carbon emissions by -0.004.

Table 5. Short-Term Estimation Results

Variable	Coefficient	Std. Error	t-Statistics	Prob.
COINTEQ01	-0.921317	0.232889	-3.956027	**0.0001***
D(CO2(-1))	0.247421	0.197906	1.250198	0.2144
D(CO2(-2))	0.100856	0.157708	0.639506	0.5241
D(URB)	1.275032	1.576112	0.808973	0.4206
D(URB(-1))	-6.397146	5.693202	-1.123646	0.2641
D(URB(-2))	6.565026	6.362202	1.031879	0.3048
D(URB(-3))	-0.717922	0.628312	-1.142619	0.2562
D(FDI)	-0.003512	0.007392	-0.475096	0.6358
D(FDI(-1))	0.002942	0.009085	0.323826	0.7468
D(FDI(-2))	0.004239	0.008445	0.501916	0.6169
D(FDI(-3))	0.013197	0.014119	0.934676	0.3524
D(POP)	199.6564	190.1859	1.049796	0.2966
D(POP(-1))	65.18307	58.46107	1.114982	0.2678
D(POP(-2))	-175.7242	101.3539	-1.733768	0.0863
D(POP(-3))	-33.33030	71.28147	-0.467587	0.6412
D(GDP)	0.009151	0.006392	1.431638	0.1556
D(GDP(-1))	0.005554	0.008513	0.652374	0.5158
D(GDP(-2))	0.007998	0.009158	0.873299	0.3848
D(GDP(-3))	0.005796	0.008336	0.695277	0.4886
C	-8.277888	2.367100	-3.497059	0.0007

Source: Secondary (processed) data, 2023

Table 5 shows the results of the Error Correction Term (ECT), where the coefficient is negative and significant with an alpha value of 0.000. These findings indicate that the independent variables (urbanization, foreign direct investment, population, and economic growth) affect carbon emissions in the short term in ASEAN countries.

Table 6. Cross-Section Short-Run ECT Coefficients (1)

Variable	INDONESIAN		MALAYSIA		THAILAND		PHILIPPINES	
	Koef.	Prob.	Koef.	Prob.	Koef.	Prob.	Koef.	Prob.
COINTEQ01	-1.887217	0.0001*	-1.618350	0.0001*	-0.155565	0.0017*	-1.137061	0.0000*
D(CO2(-1))	1.336308	0.0001*	0.891632	0.0005*	-0.018651	0.4989	-0.038763	0.0083*
D(CO2(-2))	0.478717	0.0003*	0.712633	0.0001*	0.400200	0.0002*	-0.290847	0.0000*
D(URB)	0.040338	0.0207*	0.574601	0.0000*	0.050815	0.0000*	-0.060355	0.0000*
D(URB(-1))	0.118960	0.0048*	-0.214054	0.0000*	-0.115091	0.0000*	0.294915	0.0000*
D(URB(-2))	-0.241825	0.0000*	-0.317703	0.0000*	0.052141	0.0000*	-0.129479	0.0000*
D(URB(-3))	0.026125	0.0007*	0.295496	0.0000*	0.011378	0.0001*	0.385103	0.0000*
D(FDI)	-0.006816	0.0000*	-0.016957	0.0000*	-0.009260	0.0000*	-0.029371	0.0000*
D(FDI(-1))	-0.000701	0.0000*	-0.006183	0.0000*	-0.010640	0.0000*	-0.030706	0.0000*
D(FDI(-2))	4.05E-05	0.0278*	-0.004276	0.0000*	-0.011035	0.0000*	-0.025469	0.0000*
D(FDI(-3))	-0.017085	0.0000*	0.006492	0.0000*	-0.008461	0.0000*	-0.008862	0.0000*
D(POP)	-158.5709	0.8866	-80.35140	0.7970	19.56929	0.9937	48.16675	0.7883
D(POP(-1))	331.6025	0.9483	107.2515	0.9331	-68.67666	0.9872	6.094999	0.9878
D(POP(-2))	-326.7058	0.9412	-32.11821	0.9798	115.7941	0.9747	64.39610	0.8874
D(POP(-3))	187.9571	0.8794	5.906401	0.9827	-57.84706	0.9783	-55.18329	0.7185
D(GDP)	0.011657	0.0000*	0.005893	0.0000*	0.003070	0.0000*	0.008731	0.0000*
D(GDP(-1))	0.004929	0.0000*	0.010375	0.0000*	0.002379	0.0000*	0.010308	0.0000*
D(GDP(-2))	0.001764	0.0000*	0.010229	0.0000*	0.000162	0.0000*	0.003734	0.0000*
D(GDP(-3))	0.002331	0.0000*	8.02E-07	0.7777	0.002757	0.0000*	0.003791	0.0000*
C	-18.79938	0.2388	-13.87234	0.1054	-1.400164	0.2997	-11.44087	0.0392

Source: Secondary (processed) data (2023).

Tables 6 and 7 in this study provide important insights into the characteristics of adjustment speed and short-term fluctuations, as well as the Error Correction Term (ECT) coefficients for each ASEAN country examined, as evidenced by p-values less than 0.05. The short-term variation of the independent variables indicates that these variables have a substantial impact on carbon emissions in each country. Countries with rapid adjustment speeds include Indonesia and Malaysia, as reflected in their higher coefficient values compared to other countries.

Table 7. Cross-Section Short-Run ECT Coefficients (2)

Variable	BRUNEI		VIETNAMESE		LAOS		MYANMAR	
	Koef.	Prob.	Koef.	Prob.	Koef.	Prob.	Koef.	Prob.
COINTEQ01	-1.080634	0.0006*	-0.146638	0.0008*	-0.328832	0.0000*	-1.016237	0.0025*
D(CO2(-1))	-0.292267	0.0070*	0.106426	0.0056*	-0.045875	0.1936	0.040563	0.5675
D(CO2(-2))	-0.160818	0.0144*	-0.596043	0.0000*	0.327361	0.0015*	-0.064359	0.2133

Variable	BRUNEI		VIETNAMESE		LAOS		MYANMAR	
	Koef.	Prob.	Koef.	Prob.	Koef.	Prob.	Koef.	Prob.
D(URB)	-2.319178	0.7577	-0.488015	0.0003*	0.316439	0.0006*	12.08561	0.9499
D(URB(-1))	-4.665052	0.6252	-0.219072	0.0058*	-0.329851	0.0025*	-46.04792	0.9530
D(URB(-2))	1.765644	0.7722	0.029421	0.7731	0.291851	0.0036*	51.07016	0.9584
D(URB(-3))	-2.999554	0.0996	0.939855	0.0006*	-0.408421	0.0002*	-3.993355	0.9953
D(FDI)	0.019426	0.0000*	-0.006014	0.0000*	-0.014492	0.0000*	0.035389	0.0000*
D(FDI(-1))	0.010530	0.0000*	-0.002011	0.0000*	0.004405	0.0000*	0.058842	0.0000*
D(FDI(-2))	0.020823	0.0000*	-0.005788	0.0000*	0.006301	0.0000*	0.053314	0.0000*
D(FDI(-3))	0.016135	0.0000*	0.003524	0.0000*	0.005334	0.0000*	0.108499	0.0000*
D(POP)	1487.911	0.9957	-24.58335	0.9918	309.2796	0.9263	-4.170180	0.9999
D(POP(-1))	76.89208	1.0000	4.833795	0.9993	-181.8262	0.9780	245.2926	0.9969
D(POP(-2))	-796.1160	0.9992	-118.3092	0.9650	-144.6263	0.9894	-168.1081	0.9976
D(POP(-3))	-485.7890	0.9982	123.7207	0.8343	18.86056	0.9957	-4.267774	0.9999
D(GDP)	0.045463	0.0000*	0.013183	0.0000*	-0.020650	0.0000*	0.005859	0.0002*
D(GDP(-1))	0.043417	0.0000*	0.004743	0.0000*	-0.044589	0.0000*	0.012868	0.0048*
D(GDP(-2))	0.051360	0.0000*	0.004205	0.0000*	-0.038401	0.0000*	0.030929	0.0004*
D(GDP(-3))	0.013403	0.0001*	-0.017116	0.0000*	-0.016893	0.0000*	0.058093	0.0000*
C	-4.153572	0.1517	-1.398345	0.3255	-2.621627	0.0113	-12.53681	0.6037

Source: Secondary (processed) data (2023).

Table 8. Granger Causality Test Results

Hipotesis Null:	Obs	F-Statistik	Prob.
URB does not have causality towards CO2	240	0.60372	0.5476
CO2 does not have causality towards URB		0.00337	0.9966
FDI does not have causality towards CO2	240	0.46902	0.6262
CO2 does not have causality towards FDI		2.15646	0.1180
POP does not have causality towards CO2	240	1.90782	0.1507
CO2 does not have causality towards POP		0.48570	0.6159
GDP does not have causality towards CO2	240	0.30929	0.7343
CO2 does not have causality towards GDP		0.85303	0.4274

Source: Secondary (processed) data (2023).

The Granger Causality Test results presented in Table 7 provide crucial insights into the relationships between various economic and environmental variables. The null hypothesis for each test is that there is no Granger causality between the first and second variables. Each test reports the F-statistic and p-value. The first hypothesis tests whether there is Granger causality between Urbanization (URB) and CO2. The statistical analysis yields an F-statistic of 0.60372 and a p-value of 0.5474. Since the p-value is greater than 0.05, it can be concluded that there is no evidence of Granger causality between URB and CO2.

The second null hypothesis, which examines the relationship between Foreign Direct Investment (FDI) and CO2, also indicates no causality. This is supported by an F-statistic of 0.46902 and a p-value of 0.6262. Furthermore, there is no significant causal relationship between Population (POP) and CO2, with an F-statistic of

1.90782 and a p-value of 0.1507 for the null hypothesis that POP does not Granger-cause CO2. Lastly, the Granger causality test between GDP and CO2 also shows no significant causal relationship, with an F-statistic of 0.30929 and a p-value of 0.7343 for the null hypothesis that GDP does not Granger-cause CO2. Overall, these results indicate that the tested variables do not exhibit significant Granger causality with CO2 emissions over the sample period from 1990 to 2022. This suggests that changes in one variable cannot be used to predict changes in another variable in the context of Granger causality analysis. The variables move independently of each other, implying that changes in URB, FDI, POP, and GDP do not directly influence or are influenced by changes in CO2 emissions.

The findings indicate a positive relationship between urbanization and carbon emissions in ASEAN countries, driven by several factors. Urbanization directly increases energy consumption due to heightened demands for infrastructure and urban facilities, such as high-rise buildings, shopping centers, and residential areas, which require significant energy for lighting, heating, cooling, and other activities (Yuan Wang et al., 2016). Additionally, urbanization fosters economic growth and industrialization, leading to increased fossil fuel use and exacerbated carbon emissions (Hewage et al., 2022). As urban populations grow, the demand for transportation, housing, and public amenities rises, contributing to higher carbon emissions over time (Perwithosuci et al., 2022). Rapid urbanization often results in increased energy consumption, especially from fossil fuels, leading to a short-term surge in carbon dioxide (CO2) emissions. Research indicates that higher urbanization contributes to increased energy consumption and CO2 emissions, reflecting the broader impact of urban growth on environmental sustainability (Widyawati et al., 2021).

The author's findings indicate that foreign direct investment (FDI) plays a significant role in increasing carbon emissions in ASEAN countries both in the long term and the short term. In ASEAN nations, FDI is often directed towards infrastructure development that heavily relies on fossil fuels, such as coal and oil. This dependence reinforces the use of environmentally unfriendly energy sources, significantly elevating carbon emissions over time. As a result, although FDI can stimulate economic growth and accelerate infrastructure development, its negative environmental impact, particularly the increase in carbon emissions, is a serious issue that needs to be addressed through more sustainable policies (Rahman et al., 2023). Many multinational companies relocating to ASEAN countries frequently bring older, less efficient technologies that were phased out in their home countries. The use of these technologies can further increase carbon emissions due to their lower energy efficiency compared to newer technologies. Additionally, the lack of stringent environmental standards in some ASEAN countries may exacerbate this situation, allowing companies to continue using more polluting technologies. This poses a significant challenge to climate change mitigation efforts and requires stricter policies to promote the adoption of environmentally friendly technologies and enhance energy efficiency in the region's industries (Zhu et al., 2016).

These findings align with the research conducted by Opoku & Boachie (2020), which found that foreign direct investment (FDI) increases carbon emissions by encouraging the transfer of high-emission production units from developed countries to developing ones. Additionally, investments in industries reliant on fossil fuels further exacerbate carbon emissions. ASEAN countries often have weaker environmental regulations compared to developed nations, allowing foreign companies to operate more polluting facilities at lower costs, thus increasing carbon emissions in the region (Ridzuan et al., 2014).

The impact of population on carbon emissions in ASEAN countries affects both short-term and long-term carbon emissions. In the short term, an increase in population is directly correlated with higher carbon emissions due to greater energy consumption and economic activities. Research has demonstrated that population growth significantly contributes to CO2 emissions across ASEAN countries, with the effect of population-increasing emissions in all countries in the region (Hariani et al., 2022. Additionally, a positive correlation has been found between population and carbon emissions, further exacerbating carbon emission issues in the short term (Perwithosuci et al., 2022).

Population growth often goes hand in hand with urbanization, which in turn increases the demand for resources and energy. As more people move to urban areas, there is a rise in the need for housing, transportation, and various other infrastructure services. Rapid urbanization leads to lifestyle changes, where communities tend to adopt higher consumption patterns and more intensive energy use (Thangaiyarkarasi & Vanitha, 2021). Furthermore, large-scale infrastructure projects such as highways, skyscrapers, and industrial facilities require substantial amounts of energy and materials, often sourced from environmentally harmful origins. All these factors collectively contribute to increased carbon emissions, exacerbating climate change issues. Therefore, the challenge lies in managing urbanization sustainably to meet the needs of a growing population without compromising the environment (Yuan Wang et al., 2016).

Economic growth exhibits a negative coefficient in the ASEAN countries studied for several reasons. Firstly, the Environmental Kuznets Curve (EKC) describes the relationship between economic growth and environmental degradation. In the early stages of economic growth, carbon emissions increase with industrialization and urbanization. However, once a certain income level is reached, countries begin investing in cleaner technologies and improving energy efficiency, leading to a reduction in carbon emissions. This is confirmed by research indicating that in some ASEAN countries, increases in GDP in the long term reduce carbon emissions (Saboori & Sulaiman, 2013). Secondly, as economic growth progresses, ASEAN countries tend to increase investments in clean technologies and renewable energy. These investments help reduce the carbon intensity of economic activities and lower carbon emissions in the long term (Pratama et al., 2021). Thirdly, economic growth is often accompanied by improvements in energy efficiency. More efficient technologies reduce energy consumption per unit of output, which in turn lowers carbon emissions. Studies have shown that increased energy efficiency contributes to a reduction in carbon emissions in ASEAN countries (Jie Zhang et al., 2020). Economic diversification plays a crucial role; as economies grow and diversify, they tend to shift from highly polluting industries to more sustainable and less carbon-intensive sectors, thereby reducing overall emissions (Lieu & Ngoc, 2023).

5. CONCLUSION

This study aims to examine the impact of urbanization, foreign direct investment (FDI), population, and economic growth on carbon emissions in ASEAN countries using the ARDL method. The analysis results indicate that both in the long term and short term, the variables of urbanization, FDI, and population have a positive and significant effect on carbon emissions. This suggests that increases in these three variables tend to elevate carbon emissions in ASEAN countries. However, economic growth presents different results. Although it has a significant effect, the coefficient for economic growth is negative. This indicates that increased economic growth actually contributes to a reduction in carbon emissions in both the long term and short term. These findings suggest that economic growth in ASEAN countries may be associated with the adoption of more environmentally friendly technologies or economic policies that support emission reductions. In the Granger causality testing, no causality was found between the independent variables and carbon emissions. This means that changes in urbanization, FDI, population, and economic growth do not directly cause changes in carbon emissions, and vice versa.

The implications of this study are significant for policymakers in ASEAN countries. The results highlight the need for more sustainable management strategies for urbanization, FDI, and population to reduce carbon emissions. Additionally, the findings suggest that economic growth can be directed to support emission reduction efforts by adopting clean technologies and effective environmental policies. Limitations of this study include the use of aggregate data, which may not fully reflect the individual dynamics of each ASEAN country. Therefore, further research is recommended to conduct a more in-depth analysis at the individual country level and to consider additional variables that may affect carbon emissions.

5.1. Managerial Implication

Based on the findings of this study, there are several important managerial implications for policymakers and business managers in ASEAN countries. First, urbanization should be managed sustainably by improving public transportation efficiency and promoting green development. Second, foreign investment should be directed towards environmentally friendly sectors with incentives for green technology. Third, controlling population growth through family planning policies and environmental education can help mitigate negative impacts on carbon emissions. Fourth, economic growth needs to be aligned with carbon emission reduction efforts through the adoption of clean technologies and green economic policies. Fifth, environmental policies and incentives such as carbon taxes and subsidies for renewable energy should be implemented and their effectiveness monitored. Lastly, regional and international collaboration should be enhanced to share technology and resources in efforts to reduce carbon emissions. By taking these measures, ASEAN countries can achieve sustainable economic growth while reducing carbon emissions.

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