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The Impact of Economic Growth, Industrialization, and Population on CO_2 Emissions in ASEAN

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ABSTRACT

Purpose: This study examines the effects of economic growth, industrial value added, and population on carbon dioxide emissions in five ASEAN countries and tests the proposed relationships among these variables.
Research Method: A quantitative panel-data design was applied to Indonesia, Malaysia, the Philippines, Thailand, and Vietnam during 2015–2024, producing 50 observations. Data were obtained from international databases and analyzed using panel-data regression. The Chow and Hausman tests selected the Fixed Effect Model, supported by normality, heteroscedasticity, and multicollinearity tests.
Results and Discussion: Industrial value added positively and significantly affects carbon emissions, with a coefficient of 0.8179 and a p-value of 0.0000. Population also has a positive and significant effect, with a coefficient of 1.5385 and a p-value of 0.0014. Economic growth has no significant effect. The model explains 98.62% of the variation in carbon emissions. These findings show that industrialization and population growth are the main emission drivers in the selected ASEAN countries.
Implications: ASEAN governments should promote industrial decarbonization, renewable energy, clean technology, sustainable urban planning, and country-specific environmental policies.
Originality: This study provides recent comparative evidence by accounting for country-specific heterogeneity through the Fixed Effect Model.

Keywords: ASEAN; carbon emissions; economic growth; industrial value added; population.

1. Introduction

Climate change constitutes one of the most pressing global environmental challenges of the 21st century, posing significant threats to ecosystems, public health, and economic stability. This phenomenon is characterized by rising global mean temperatures, shifts in climatic patterns, sea-level rise, and an increasing frequency of extreme weather events (Susilowati *et al.,* 2025). Greenhouse gas (GHG) emissions, particularly carbon dioxide (CO_2) derived from the combustion of fossil fuels, serve as the primary driver of anthropogenic climate change. The Southeast Asian region is notably susceptible to these impacts, including sea-level rise, intensifying extreme weather events, and alterations in precipitation regimes (Tran & Tran, 2025).

The ASEAN region occupies a strategically significant position as one of the world's fastest-growing economic blocs, endowed with abundant natural resources and characterized by a youthful

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demographic profile alongside accelerating urbanization. Over recent decades, ASEAN member states have experienced remarkable economic growth, propelled by industrialization, trade liberalization, and substantial inflows of foreign direct investment. Nevertheless, the confluence of population expansion, continued industrial activity, and elevated standards of living has precipitated a pronounced escalation in CO_2 emissions across the region since the 1990s (Anser *et al.,* 2025). By 2020, fossil fuel combustion and cement manufacturing collectively accounted for approximately 1.65 gigatons (Gt) of CO_2 emissions within ASEAN economies (Anser *et al.,* 2025).

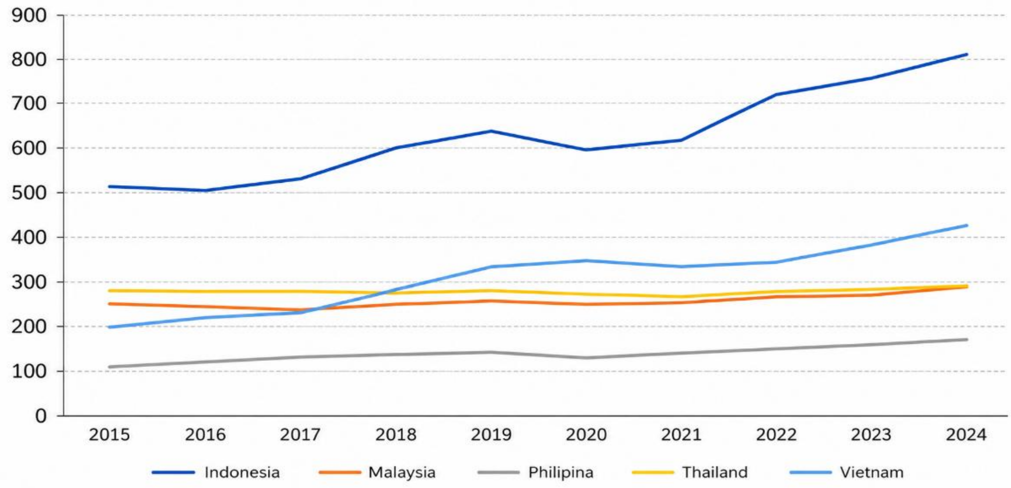

Figure 1. Carbon dioxide (CO2) emissions of five ASEAN countries (Indonesia, Malaysia, the Philippines, Thailand, and Vietnam)

Between 2015 and 2024, data on total carbon dioxide (CO2) emissions—excluding LULUCF (Land Use, Land-Use Change, and Forestry) and measured in Mt CO2e (million tonnes of CO2 equivalent)—revealed starkly contrasting trends among five ASEAN nations. This metric specifically excludes carbon sequestration and emissions from the land and forestry sectors, thereby providing a purer reflection of emissions stemming from fossil fuel combustion, industry, and chemical processes—the primary drivers of human-induced climate change.

Under this definition, Indonesia stands out as the region's largest emitter; its emissions surged from 512.4 Mt CO2 in 2015 to 812.2 Mt CO2e in 2024. Although the country experienced temporary slowdowns in 2016 and 2020 due to global economic shocks, emissions rebounded and grew exponentially in the post-pandemic period. A particularly significant shift occurred in Vietnam, where emissions nearly doubled—rising from 200.8 to 430.8 Mt CO2—reflecting the country's emergence as a manufacturing hub and the massive expansion of its coal-fired power generation capacity. Notably, Vietnam's emissions trend bucked the global decline seen in 2020, continuing instead to climb steadily—a sign of unstoppable industrial growth.

In contrast, Thailand and Malaysia exhibited marked stagnation: Thailand's emissions remained largely flat within the 268–286 Mt CO2e range, while Malaysia saw only a moderate increase from 252.9 to 296.0 Mt CO2. Both nations appear to have successfully curbed the growth of industrial emissions, avoiding significant spikes—likely due to energy transitions or a slowdown in the expansion of heavy industry sectors. Meanwhile, the Philippines—with the lowest emission volume among the five countries, ranging from 113.2 to 174.1 Mt CO2—exhibits steady, gradual growth without extreme fluctuations. Overall, based on the classification excluding LULUCF, the data confirms that Indonesia and

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Vietnam are the primary drivers of rising industrial carbon emissions in ASEAN; Malaysia and Thailand are in a plateau phase; and the Philippines is moving slowly but surely along a low-growth trajectory.

This phenomenon raises a crucial question regarding the relationship between economic activity and environmental degradation in the region. According to Dinda (2004), economic growth and carbon dioxide emissions are closely linked through the Environmental Kuznets Curve (EKC). There are two forms of the EKC: the inverted U-shaped curve (where pollution levels decline as economic growth rises in the second stage) and the U-shaped curve (where pollution levels rise as economic growth rises in the second stage) (Dinda, 2004).

The remainder of this paper is organized as follows. Section 2 provides a literature review and hypothesis development. Section 3 presents the research method and design. Section 4 provides the results and discussion. Section 5 presents Concluding Remarks and Recommendations.

2. Literature Review and Hypothesis Development

2.1 *Environmental Kuznets Curve (EKC)*

The Environmental Kuznets Curve (EKC) is a frequently cited hypothesis in studies of the economy-environment relationship, positing that when national income reaches a sufficiently high level, pollution tends to decrease. The EKC hypothesis is validated when economic growth initially increases emissions but reduces them at higher income levels (Dinda, 2004). Research in seven ASEAN countries from 2011 to 2022 supports the EKC hypothesis, revealing that urbanization and economic growth significantly increase carbon emissions (Hamim & Jalil, 2024). Othman *et al.,* (2024) examined the relationship between economic growth, FDI, technological advancement, household consumption, and greenhouse gas emissions among ASEAN countries. Using panel data from 1990 to 2022 for seven ASEAN countries, this study employed Pooled Mean Group (PMG) analysis and found support for the validity of the EKC hypothesis in the ASEAN region, indicating an inverted U-shaped relationship between economic growth and GHG (Othman *et al.,* 2024).

Santana & Maria (2024) tested the EKC hypothesis in ASEAN member countries from 2015 to 2022. The results showed that the EKC hypothesis is confirmed in ASEAN member countries, with the turning point of the relationship between GDP per capita and CO_2 emissions in the ASEAN region at 17.11 trillion dollars (Santana & Maria, 2024). Singapore and Brunei Darussalam are two of the 11 ASEAN countries that have passed the scale and structural effect phases of the Environmental Kuznets Curve, while others remain on the left side of the EKC (Santana & Maria, 2024). Nguyen & Nguyen (2025) tested the EKC hypothesis in five developing ASEAN countries (Indonesia, Malaysia, Philippines, Thailand, and Vietnam) from 1990 to 2024. The results confirmed the existence of an EKC relationship between income and CO_2 emissions per capita, with a clear turning point (Nguyen & Nguyen, 2025). Claire & Widyawati (2023) examined the relationship between ASEAN industrialization, renewable energy, and CO_2 emissions. The findings revealed the existence of EKC in ASEAN in the short term for most member countries and found that renewable energy mediates the relationship between industrial value added and CO_2 emissions (Claire & Widyawati, 2023).

2.2 *Economic Growth and Carbon Emissions*

Economic growth, measured through Gross Domestic Product (GDP), has a relationship with CO_2 emission levels. In the ASEAN region, research using the Panel ARDL approach by Susilowati *et al.,* (2025)

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showed that in the long term, GDP per capita growth, energy intensity, and sectoral structure have a significant positive influence on carbon emissions, while renewable energy has a negative but insignificant influence (Susilowati *et al.,* 2025). Ali (2025) investigated the EKC hypothesis and drivers of CO_2 emissions in nine ASEAN economies (Brunei, Cambodia, Indonesia, Laos, Malaysia, Philippines, Singapore, Thailand, Vietnam) during the 1990-2025 period. The results validated the inverted U-shaped EKC, with emissions peaking at around USD 47,187 per capita—a threshold that most ASEAN countries have not yet reached (Ali, 2025). However, Tran & Tran (2025) found that the fixed effects model shows GDP has a negative relationship with CO_2, while urbanization and industrialization have positive effects (Tran & Tran, 2025). These findings indicate that although ASEAN has pursued economic growth, this does not always cause a proportional increase in CO_2, and industrialization and urbanization are critical factors associated with increased emissions (Tran & Tran, 2025).

2.3 Industrial Value Added and Carbon Emissions

Industrialization has a significant contribution to increasing carbon emissions. Claire & Widyawati (2023) found that renewable energy mediates the relationship between industrial value added and CO_2 emissions, with renewable energy adoption changing the turning point of CO_2 emissions per capita during industrialization in several ASEAN countries (Claire & Widyawati, 2023). Ali (2025) found that renewable energy consumption emerges as a strong emission mitigator, while industrial value added and population growth strengthen emissions, and service sector expansion shows mitigation effects (Ali, 2025). Nguyen & Nguyen (2025) also found that industrialization increases emissions, while urbanization has an emission reduction effect (Nguyen & Nguyen, 2025). Research on the dynamic relationship between industrial CO_2 emissions, economic growth, and manufacturing value added in ten ASEAN countries during the 2014-2023 period using the Panel VAR approach found a significant relationship between the three variables (Aliyuddin *et al.,* 2026).

2.4 Population and Carbon Emissions

Population is an important factor affecting carbon emissions. Santana & Maria (2024) found that population size, foreign investment, and trade openness significantly increase carbon emissions in the ASEAN region, while energy transition can reduce carbon emissions although not significantly (Santana & Maria, 2024). Ali (2025) found that industrial value added and population growth strengthen CO_2 emissions in nine ASEAN economies. Anser *et al.,* (2025) affirmed that population growth, industrialization, and rising living standards have contributed to the sharp increase in CO_2 emissions in ASEAN since the 1990s. However, economic growth, population expansion, and increasing energy intensity significantly contribute to the continuous increase in CO_2 emissions across the region (Anser *et al.,* 2025).

2.5 Panel Data Regression and Fixed Effect Model

Panel data regression is an econometric technique that combines cross-section and time series data. This approach allows researchers to capture heterogeneity between individuals (countries) and changes over time simultaneously. The Chow Test is used to choose between the Common Effect Model (CEM) and the Fixed Effect Model (FEM), where if the probability value < 0.05, FEM is selected. The Hausman Test is used to choose between the Fixed Effect Model (FEM) and the Random Effect Model (REM),

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where if the probability value is < 0.05, FEM is selected. Ghofur *et al.,* (2026) examined the relationship between renewable energy, fossil fuel consumption, CO_2 emissions, and economic growth in ASEAN. By analyzing data from Indonesia, Malaysia, Thailand, Singapore, Philippines, and Vietnam (2000-2023), statistical tests confirmed the Fixed Effects Model (FEM) as the optimal model that controls for unobserved national characteristics (Ghofur *et al.,* 2026). Tran & Tran (2025) used panel data regression models to examine the impact of economic growth, urbanization, industrialization, and other variables on CO_2 emissions, and found that the fixed effects model shows GDP has a negative relationship with CO_2, while urbanization and industrialization have positive effects (Tran & Tran, 2025). Hamim & Jalil (2024) used panel data analysis applying Pooled Ordinary Least Squares and Fixed Effects Models, revealing that urbanization and economic growth significantly increase carbon emissions (Hamim & Jalil, 2024).

H1: *Economic growth has a significant positive effect on carbon dioxide emissions in 5 ASEAN countries.*

H2: *Industrial value added has a significant positive effect on carbon dioxide emissions in 5 ASEAN countries.*

H3: *Population has a significant positive effect on carbon dioxide emissions in 5 ASEAN countries.*

3. Research Method

3.1 Type and Source of Data

This study uses panel data, which combines time series and cross-sectional data. The data covers 5 ASEAN member countries with an observation period of 2015-2024, resulting in a balanced panel of 50 total observations. The sample selection is based on the five ASEAN countries with the highest carbon emission growth rates: Indonesia, Philippines, Malaysia, Thailand, and Vietnam (Prinadi *et al.,* 2022).

The variables in this study consist of:

- Dependent Variable (Y): Carbon Dioxide Emissions (CO_2) in natural logarithmic form [LOG(Y)]
- Independent Variable (X1): Economic Growth (GDP)
- Independent Variable (X2): Industrial Value Added in natural logarithmic form [LOG(X2)]
- Independent Variable (X3): Population in natural logarithmic form [LOG(X3)]

Data sources are from international institutions such as the World Bank (World Development Indicators) and the International Energy Agency (Santana & Maria, 2024).

3.2 Panel Data Regression Model

The panel data regression model used in this study is:

$$LOG(Y)_{it} = \alpha + \beta_1 X1_{it} + \beta_2 LOG(X2)_{it} + \beta_3 LOG(X3)_{it} + \varepsilon_{it}$$

Where:

$LOG(Y)_{it}$	=	Carbon dioxide emissions of country i in period t
$X1_{it}$	=	Economic growth of country i in period t
$LOG(X2)_{it}$	=	Industrial value added of country i in period t
$LOG(X3)_{it}$	=	Population of country i in period t
α	=	country-specific effects (cross-section fixed effects)
$\beta_1, \beta_2, \beta_3$	=	Regression coefficients
ε_{it}	=	Error term

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3.3 *Data Analysis Techniques*

3.3.1 *Chow Test*

The Chow Test is used to choose between the Common Effect Model (CEM) and the Fixed Effect Model (FEM) (Ghofur *et al.,* 2026). The hypotheses in the Chow Test are:

- H_0: CEM (Common Effect Model) is more appropriate
- H_1: FEM (Fixed Effect Model) is more appropriate

Decision criteria: if the probability value is < 0.05, H_0 is rejected, and FEM is selected.

3.3.2 *Hausman Test*

The Hausman Test is used to choose between the Fixed Effect Model (FEM) and the Random Effect Model (REM). The hypotheses in the Hausman Test are:

- H_0: REM (Random Effect Model) is more appropriate
- H_1: FEM (Fixed Effect Model) is more appropriate

Decision criteria: if the probability value is < 0.05, H_0 is rejected, and FEM is selected.

3.3.3 *Normality Test*

The normality test is used to determine whether the residuals of the regression model are normally distributed. The Jarque-Bera test is employed; if the probability value is> 0.05, the residuals are normally distributed.

3.3.4 *Heteroscedasticity Test*

The heteroscedasticity test is used to determine whether there is variance inequality in the regression model residuals. The test is conducted by regressing the absolute residual (ABS_RES) against the independent variables. If the probability values of all variables are> 0.05, there is no heteroscedasticity problem.

3.3.5 *Multicollinearity Test*

The multicollinearity test is used to determine whether there is a high correlation among independent variables. The test is conducted using correlation analysis; if the correlation coefficient between independent variables is < 0.80, there is no multicollinearity problem.

Table 1. Variables and Measurement

Variable	Code	Indicator	Major Reference
Economic Growth	X1	Gross Domestic Product (GDP) growth rate	(Susilowati *et al.,* 2025; Tran & Tran, 2025)
Industrial Value Added	LOG X2	Value added in industry sector (logarithmic form)	(Santana & Maria, 2024; Anser *et al.,* 2025
Population	LOG X3	Total population (logarithmic form)	(Claire & Widyawati, 2023; Ali, 2025)
Carbon Dioxide Emissions	LOG Y	CO_2 emissions from fossil fuel combustion (logarithmic form)	(Othman *et al.,* 2024; Nguyen & Nguyen, 2025)

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4. Results and Discussion

4.1 Analysis Results

4.1.1 *Model Selection Test Results*

4.1.1.1 *Chow Test*

Table 2. Chow Test

Redundant Fixed Effects Tests
Equation: Untitled
Test cross-section fixed effects

Effects Test	Statistic	d.f.	Prob.
Cross-section F	146.190723	(4,42)	0.0000
Cross-section Chi-square	135.144934	4	0.0000

Based on the data processing results, the Chow Test produced a probability value of 0.000. Since the probability value (0.000) < 0.05, H_0 is rejected, so the selected model is the Fixed Effect Model (FEM). This result is consistent with the research of Ghofur *et al.,* (2026), which also used the Chow Test and selected FEM as the best model for panel data analysis in ASEAN.

The Chow Test results indicate that there are differences in intercepts between ASEAN countries in influencing carbon dioxide emissions. These differences can be caused by country-specific characteristics such as environmental policies, economic structure, technology levels, and other time-invariant factors, as explained by Ghofur *et al.,* (2026) that FEM controls for unobserved national characteristics.

4.1.1.2 *Hausman Test*

Table 3. Hausman Test

Correlated Random Effects - Hausman Test
Equation: Untitled
Test cross-section random effects

Test Summary	Chi-Sq. Statistic	Chi-Sq. d.f.	Prob.
Cross-section random	9.426723	3	0.0241

Based on data processing results, the Hausman Test produced a probability value of 0.0241. Since the probability value (0.0241) < 0.05, H_0 is rejected, so the selected model is the Fixed Effect Model (FEM). This result confirms that FEM is the best model for analyzing the influence of independent variables on carbon dioxide emissions in the ASEAN region (Ghofur *et al.,* 2026).

The Hausman Test results show that there is a correlation between the independent variables and individual effects (country-specific effects), so the Random Effect Model (REM) is not appropriate. FEM can control for unobserved heterogeneity between countries that may be biased if using REM (Tran & Tran, 2025).

4.1.2 *Diagnostic Tests*

4.1.2.1 *Normality Test*

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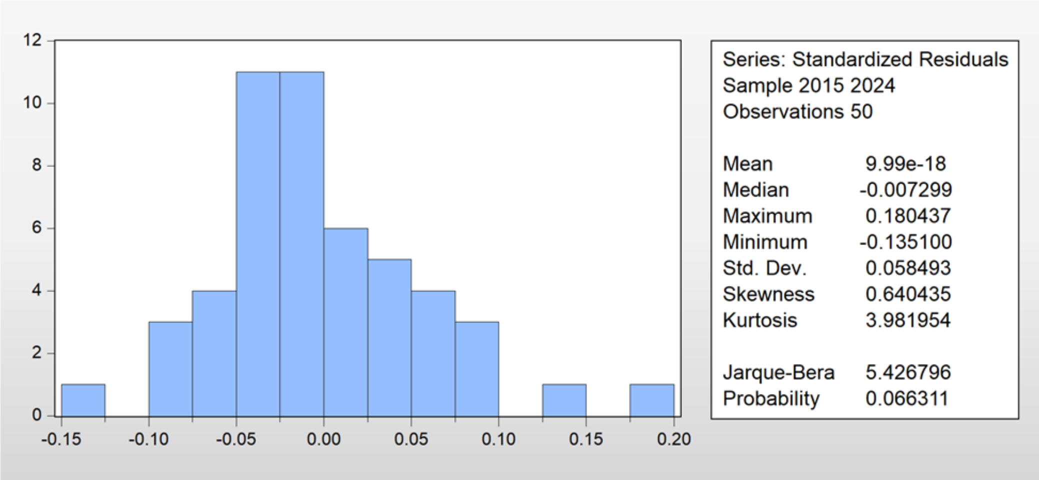

Figure 2. Normality Test

The normality test was conducted using the Jarque-Bera test to determine whether the residuals of the regression model are normally distributed. The test results show a Jarque-Bera probability value of 0.066311. Since the probability value (0.066311) > 0.05, the residuals are normally distributed. This indicates that the model meets the normality assumption required for valid statistical inference.

4.1.2.2 *Heteroscedasticity Test*

The heteroscedasticity test was conducted by regressing the absolute residual (ABS_RES) against the independent variables using the Panel Least Squares method. The test results are presented in Table 3.

Table 4. Heteroscedasticity Test Results (ABS_RES)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
X1	0.000776	0.001667	0.465790	0.6438
LOG(X2)	-0.059810	0.062563	-0.955990	0.3445
LOG(X3)	0.118238	0.263850	0.448126	0.6564
C	-1.932439	4.700681	-0.411098	0.6831

Based on the heteroscedasticity test results, all independent variables have probability values greater than 0.05 (X1: 0.6438; LOG X2: 0.3445; LOG X3: 0.6564). Therefore, H_0 is accepted, indicating that there is no heteroscedasticity problem in the regression model. This confirms that the variance of residuals is constant (homoscedastic), which is an important assumption for the validity of the regression estimates.

4.1.3.2 *Multicollinearity Test*

Table 5. Multicolinearity Test Test

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Correlation	X1	X2	X3	Y
X1	1.000000			
X2	0.070840	1.000000		
X3	0.050504	0.648896	1.000000	
Y	0.002502	0.852995	0.807831	1.000000

4.1.4 *Fixed Effect Model (FEM) Estimation Results*

The FEM estimation using the Panel Least Squares method produced the following statistical summary:

Table 6. Fixed Effect Model Estimation Results

Variable	Coefficient	Std. Error	t-Statistic	Prob.
X1	0.001623	0.002830	0.573489	0.5694
LOG(X2)	0.817906	0.106243	7.698441	0.0000
LOG(X3)	1.538472	0.448060	3.433627	0.0014
C	-25.26360	7.982527	-3.164862	0.0029
Effects Specification				
Cross-section fixed (dummy variables)				
R-squared	0.986190	Mean dependent var		5.660364
Adjusted R-squared	0.983889	S.D. dependent var		0.497750
S.E. of regression	0.063179	Akaike info criterion		-2.540031
Sum squared resid	0.167649	Schwarz criterion		-2.234107
Log likelihood	71.50077	Hannan-Quinn criter.		-2.423533
F-statistic	428.4805	Durbin-Watson stat		1.345643
Prob(F-statistic)	0.000000			

Based on the estimation results, the FEM regression equation can be written as:

$$LOG(Y) = -25.26360 + 0.001623\ X1 + 0.817906\ LOG(X2) + 1.538472\ LOG(X3) \quad (1)$$

4.2 Discussion

4.2.1 *The Effect of Economic Growth (X1) on Carbon Dioxide Emissions*

The economic growth variable (X1) has a regression coefficient of 0.001623 with a probability value of 0.5694. Since the probability value (0.5694) > 0.05, statistically, economic growth does not have a significant effect on carbon dioxide emissions in the ASEAN region at a 5% significance level. This finding shows that an increase in economic growth is not necessarily followed by a significant increase in carbon emissions in ASEAN countries. This result is consistent with the correlation analysis, which showed a near-zero correlation (0.002502) between economic growth and carbon emissions. The finding is also consistent with the research of Tran & Tran (2025), which found that the fixed effects model shows GDP has a negative relationship with CO_2, indicating that although ASEAN has pursued economic growth, this does not always cause a proportional increase in CO_2 (Tran & Tran, 2025). Susilowati *et al.*, (2025) also found that in the short term, economic growth has not shown a significant impact on emissions in ASEAN maritime states.

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Several ASEAN countries may have entered a stage where economic growth is accompanied by energy efficiency and transition to the service sector, so emissions do not increase proportionally. Susilowati *et al.,* (2025) found that the Philippines and Malaysia are beginning to show decoupling through energy efficiency and the service sector, while Vietnam and Thailand are still in the early phase of EKC (Susilowati *et al.,* 2025). However, this finding differs from several other studies that found GDP per capita has a positive and significant influence on CO_2 emissions. These differences may be caused by differences in research periods, number of sample countries, or model specifications used. Based on these findings, H1 is rejected. Economic growth does not have a significant effect on carbon dioxide emissions.

***4.2.2** The Effect of Industrial Value Added (X2) on Carbon Dioxide Emissions*

The industrial value added variable (LOG(X2)) has a regression coefficient of 0.817906 with a probability value of 0.0000. Since the probability value (0.0000) < 0.05, statistically, industrial value added has a positive and significant effect on carbon dioxide emissions in the ASEAN region at a 5% significance level. The coefficient of 0.817906 indicates that every 1% increase in industrial value added will increase carbon dioxide emissions by 0.818% (in the log-log model), assuming other variables are constant (ceteris paribus). This finding is strongly supported by the correlation analysis, which showed a very strong positive correlation (0.852995) between industrial value added and carbon emissions. This finding indicates that industrialization in the ASEAN region is still heavily dependent on fossil fuels and technologies that are not yet environmentally friendly.

This result is consistent with various previous studies. Ali (2025) found that industrial value added strengthens CO_2 emissions in nine ASEAN economies (Ali, 2025). Nguyen & Nguyen (2025) also found that industrialization increases emissions (Nguyen & Nguyen, 2025). Tran & Tran (2025) found that industrialization has a positive effect on CO_2 emissions (Tran & Tran, 2025). Claire & Widyawati (2023) found that renewable energy mediates the relationship between industrial value added and CO_2 emissions (Claire & Widyawati, 2023). High industrial value added reflects high production activity in the manufacturing sector, which is generally energy-intensive and still relies on fossil fuels. This causes an increase in carbon emissions along with increasing industrial output. Based on these findings, H2 is accepted. Industrial value added has a significant positive effect on carbon dioxide emissions.

***4.2.3** The Effect of Population (X3) on Carbon Dioxide Emissions*

The population variable (LOG(X3)) has a regression coefficient of 1.538472 with a probability value of 0.0014. Since the probability value (0.0014) < 0.05, statistically, population has a positive and significant effect on carbon dioxide emissions in the ASEAN region at a 5% significance level. The coefficient of 1.538472 indicates that every 1% increase in population will increase carbon dioxide emissions by 1.538% (in the log-log model), assuming other variables are constant (ceteris paribus). This elasticity greater than 1 indicates that population is a very dominant factor in driving the increase in carbon emissions in the ASEAN region. The correlation analysis supports this finding, showing a strong positive correlation (0.807831) between population and carbon emissions.

This result is consistent with the research of Santana & Maria (2024), which found that population size significantly increases carbon emissions in the ASEAN region (Santana & Maria, 2024). Ali (2025) also found that population growth strengthens CO_2 emissions (Ali, 2025). Anser *et al.,* (2025) affirmed that population growth, industrialization, and rising living standards have contributed to the

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sharp increase in CO_2 emissions in ASEAN since the 1990s (Anser *et al.,* 2025). Population growth increases energy demand for household needs, transportation, and other economic activities. Population growth also drives urbanization and expansion of urban areas, which in turn increases energy consumption and carbon emissions (Hamim & Jalil, 2024). Based on these findings, H3 is accepted. Population has a significant positive effect on carbon dioxide emissions.

4.3 *Model Evaluation*

4.3.1 *Coefficient of Determination (R^2)*

The R-squared value of 0.986190 indicates that collectively, the variables of economic growth (X1), industrial value added (X2), and population (X3) can explain 98.62% of the variation in carbon dioxide emissions (Y) in the ASEAN region. The Adjusted R-squared value of 0.983889, which is not far from R^2, indicates that the model has considered the number of independent variables well and there is no overfitting. This very high R^2 value is consistent with findings from other studies using FEM in the ASEAN region, where the model explains most of the variation in carbon emissions (Ghofur *et al.,* 2026; Tran & Tran, 2025).

4.3.2 *Simultaneous Significance Test (F Test)*

The F-statistic value is 428.4805 with a probability of 0.000000. Since the probability value (0.000000) < 0.05, simultaneously the three independent variables (X1, X2, X3) have a significant effect on carbon dioxide emissions (Y). This shows that the model as a whole is feasible to use to predict carbon dioxide emissions in the ASEAN region.

4.3.3 *Autocorrelation Test (Durbin-Watson)*

The Durbin-Watson statistic value is 1.345643. This value is below the upper bound (du) for detecting positive autocorrelation, indicating positive autocorrelation in the model. However, in the context of panel data with fixed effects, autocorrelation is not always a major problem because FEM already controls for heterogeneity between individuals (Ghofur *et al.,* 2026). Future research may consider using Driscoll-Kraay standard errors to address potential heteroscedasticity and autocorrelation (Ali, 2025).

4.4 *Discussion of EKC Hypothesis Confirmation*

The findings of this study provide support for the Environmental Kuznets Curve (EKC) hypothesis in the ASEAN region. The non-significant effect of economic growth on carbon emissions indicates that ASEAN countries may be approaching or have reached the turning point of the EKC curve, where economic growth no longer causes a proportional increase in emissions. This finding is consistent with Othman *et al.,* (2024), Santana & Maria (2024), and Nguyen & Nguyen (2025), who confirmed the existence of EKC in the ASEAN region. The results show that industrial value added and population are the dominant factors driving carbon emissions, while economic growth shows signs of early decoupling from emissions. This implies that ASEAN countries need to focus on two main areas for emission control: industrial sector decarbonization and population-related consumption patterns.

The dominance of industrial value added on carbon emissions indicates that industrialization in ASEAN is still ongoing with a "high carbon growth" pattern. ASEAN countries need to transition towards green industrialization by adopting clean technology and renewable energy. Claire & Widyawati (2023) showed that renewable energy mediates the relationship between industrial value added and CO_2

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emissions, with renewable energy adoption changing the turning point of CO_2 emissions per capita during industrialization (Claire & Widyawati, 2023). The very large influence of population (elasticity > 1) shows that population growth in ASEAN is a serious challenge for emission control efforts. Population control policies need to be integrated with environmental policies, including education on efficient energy consumption and sustainable urban development (Hamim & Jalil, 2024).

The selection of FEM as the best model confirms that differences in characteristics between ASEAN countries are fixed in influencing carbon emissions. Ghofur *et al.,* (2026) emphasized that by explicitly modeling heterogeneity, this study goes beyond the homogeneous panel assumption that obscures critical differences, and the results provide insights tailored to the diverse ASEAN economic-energy reality (Ghofur *et al.,* 2026). This shows that emission control policies need to consider the specific conditions of each country, including economic structure, energy mix, and national environmental policies.

The diagnostic tests confirm that the model is well-specified. The normality test results (Jarque-Bera Prob 0.066311> 0.05) indicate that the residuals are normally distributed, ensuring the validity of statistical inference. The heteroscedasticity test results (all probability values > 0.05) confirm that there is no heteroscedasticity problem, indicating that the variance of residuals is constant. The multicollinearity test confirms no high correlation among independent variables (correlation coefficient between X2 and X3 is 0.6489 < 0.80). These diagnostic results strengthen the reliability of the model estimates.

5. Concluding Remarks and Recommendation

The Chow Test produced a probability value of 0.000 < 0.05, so the selected model is the Fixed Effect Model (FEM). This shows that there are differences in intercepts between ASEAN countries in influencing carbon dioxide emissions (Ghofur *et al.,* 2026). The Hausman Test produced a probability value of 0.0241 < 0.05, confirming that the Fixed Effect Model (FEM) is the best compared to the Random Effect Model (REM). This shows that there is a correlation between the independent variables and individual effects between countries (Ghofur *et al.,* 2026).

Diagnostic tests confirm the model is well-specified: the normality test (Jarque-Bera Prob. 0.066311> 0.05) indicates normally distributed residuals; the heteroscedasticity test (all probability values > 0.05) confirms no heteroscedasticity; and the correlation analysis confirms no multicollinearity (the correlation coefficient between X2 and X3 is 0.6489 < 0.80). Correlation analysis reveals that industrial value added has a very strong positive correlation with carbon emissions (r=0.8530), followed by population (r=0.8078), while economic growth shows a very weak correlation (r=0.0025). Industrial value added (LOG X2) has a positive and significant effect on carbon dioxide emissions (coefficient 0.8179; p=0.0000). Every 1% increase in industrial value added increases carbon emissions by 0.818%. This finding is consistent with Ali (2025), Nguyen & Nguyen (2025), and Claire & Widyawati (2023). Population (LOG X3) has a positive and significant effect on carbon dioxide emissions (coefficient 1.5385; p=0.0014). Every 1% increase in population increases carbon emissions by 1.538%. This finding is consistent with Santana & Maria (2024), Ali (2025), and Anser *et al.,* (2025). Economic growth (X1) does not have a significant effect on carbon dioxide emissions (p=0.5694), indicating potential decoupling between economic growth and emissions in the ASEAN region (Tran & Tran, 2025; Susilowati *et al.,*

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2025). The model has very high predictive capability, with an R-squared of 98.62% and an F-statistic of 428.48 (p=0.0000).

The research results confirm the Environmental Kuznets Curve (EKC) hypothesis in the ASEAN region as found by Othman *et al.,* (2024), Santana & Maria (2024), and Nguyen & Nguyen (2025).

This study contributes to the EKC literature by providing empirical evidence from five ASEAN countries with the highest carbon emission growth rates. The findings support the EKC hypothesis and extend the understanding of the roles of industrialization and population as distinct drivers of carbon emissions, beyond the traditional focus on economic growth. The study demonstrates the importance of using Fixed Effect Models to capture country-specific heterogeneity in panel data analysis. The diagnostic tests confirm the robustness of the model specification. Practical Implications: The findings indicate that industrialization and population growth are the main drivers of carbon emissions in ASEAN. Policymakers need to: (1) accelerate energy transition in the industrial sector by promoting renewable energy adoption and clean technology (Claire & Widyawati, 2023; Ali, 2025); (2) integrate population control policies with environmental policies, including spatial planning and sustainable urban development (Hamim & Jalil, 2024); (3) strengthen institutional frameworks and environmental governance to ensure policy effectiveness (Ali, 2025); and (4) adopt country-specific approaches considering the unique characteristics of each ASEAN member state (Ghofur *et al.,* 2026). The non-significant effect of economic growth on emissions provides room for optimism that ASEAN countries can achieve decoupling between economic growth and carbon emissions. The selection of FEM confirms that a "one size fits all" approach is not effective in the heterogeneous ASEAN region. Emission control policies need to consider country-specific economic structures, energy mixes, and environmental policies. ASEAN member states committed to energy targets should prioritize renewable energy implementation in their industrial sectors to achieve environmental benefits (Claire & Widyawati, 2023).

This study has several limitations that should be acknowledged. First, the research only covers five ASEAN countries with the highest carbon emission growth rates, so the results may not be generalizable to all ASEAN member states. Second, the study only includes three independent variables (economic growth, industrial value added, and population). At the same time, other factors such as renewable energy consumption, foreign direct investment, urbanization, and technological innovation may also influence carbon emissions. Third, the model shows indications of positive autocorrelation (Durbin-Watson = 1.3456), which may affect the efficiency of the estimators. Based on these limitations, future research can consider the following agendas. Expand the scope of variables by including other factors such as renewable energy consumption, foreign direct investment, urbanization, and technological innovation (Ali, 2025; Nguyen & Nguyen, 2025). Use dynamic panel methods such as GMM or Panel ARDL to provide more in-depth analysis of short-term and long-term relationships (Susilowati *et al.,* 2025; Claire & Widyawati, 2023). Consider using Driscoll-Kraay standard errors to address potential heteroscedasticity and autocorrelation (Ali, 2025). Test the Environmental Kuznets Curve (EKC) hypothesis more comprehensively by including the quadratic variable of economic growth (Othman *et al.,* 2024; Santana & Maria, 2024). Include all ASEAN member states to provide a more comprehensive picture of the region's emission dynamics. Conduct sectoral analysis to identify specific industries that are the main contributors to carbon emissions in each ASEAN country.

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Statement of Use of Generative AI

During the preparation of this work, the author used generative artificial intelligence tools to support the scientific writing process. Grammarly was used to check grammar, refine writing style, and improve clarity in scientific writing. All interpretations, analyses, and conclusions presented in this study are the sole responsibility of the author.

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