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Growth, Industrial Structure, and Carbon Emissions in ASEAN: A Panel Data Analysis

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ABSTRACT

This study examines the relationship between economic growth, industrial growth, and carbon dioxide emissions in ASEAN countries over the period 2010–2020, with particular emphasis on the interaction between economic expansion and industrial structure. Using balanced panel data from nine ASEAN economies and employing panel regression techniques, the analysis evaluates both the direct and conditional effects of growth on environmental outcomes. The results indicate that economic growth and industrial growth each have a positive and statistically significant impact on carbon emissions. More importantly, the interaction term between economic growth and industrial growth is also positive and significant, suggesting that the environmental impact of GDP growth is amplified in economies experiencing stronger industrial expansion. These findings imply that economic growth in ASEAN remains closely linked to energy-intensive industrial activities, limiting progress toward emissions reduction. By explicitly modeling the interaction between growth and industrial structure, this study contributes to the environmental economics literature by providing a more nuanced understanding of the growth–emissions nexus in developing regional contexts.

Keywords: Carbon Emissions, Economic Growth, Industrial Growth, Environmental Kuznets Curve, ASEAN

JEL Classification: D73, O47, F21, I15, F13

INTRODUCTION

In recent decades, carbon dioxide emissions have continued to increase (Peter et al., 2016). This has caused worldwide concern, especially since air pollution due to carbon pollution will have a significant impact on the environment. Air pollution is one of the negative externalities in the public economy that is a consequence of the production of goods or services (Niyazi & Eyl, 2024). The ever-increasing amount of CO_2 will reduce the quality of life and environmental sustainability (Kabir et al., 2023). The environment is also considered a factor influenced by human activities in increasing the growth and development of a country (Costantini & Monni, 2008). The biggest challenge for developing countries is how to maintain economic growth, while maintaining environmental quality at an acceptable level so that it will not damage the environment (Zafarullah & Mehnaz, 2025). Despite this growing concern, the relationship between economic expansion and environmental degradation remains theoretically and empirically contested, particularly in developing regions where growth is still strongly associated with resource-intensive production systems. This tension highlights the need for empirical studies that move beyond documenting the existence of environmental externalities and instead examine the mechanisms through which economic growth translates into rising emissions. Understanding these mechanisms is crucial, as policy responses may differ substantially depending on whether environmental degradation is driven primarily by the scale of economic activity, the structure of production, or their interaction.

A developing region that focuses on development and growth is ASEAN. ASEAN is a geopolitical and economic organization of countries in the Southeast Asian region. Increasing economic production is one of the indications of the achievement of the economic development process in ASEAN. Each country produces economic output which is assessed as national income or Gross Domestic Product (GDP). While these developments underscore ASEAN's economic dynamism, they also raise critical questions regarding the environmental implications of growth patterns that remain largely driven by industrial expansion and increasing energy demand. Rapid GDP growth, particularly when supported by manufacturing and resource-based industries, may generate heterogeneous environmental outcomes across ASEAN member states, depending on differences in industrial structure and energy intensity. Consequently, relying solely on aggregate economic indicators such as GDP may obscure the underlying channels through which economic growth contributes to environmental pressure in the region.

Over the years, ASEAN has demonstrated rapid economic development in recent decades. As a whole the region's GDP is on course to outgrow that of Japan and the EU by 2030, when it will be the fourth largest single market in the world. Factors contributing to this economic growth include the high proportion of young and educated in the population, rapid regional integration and rich natural resources. As evidenced by improvements in a number of developmental indicators, including poverty reduction, peace and stability, food and nutritional security, education,

women's empowerment, job creation, and inclusivity, the region's economic growth has also aided in social development. The environment is now more receptive to sharing best practices, which will assist build upon the achievements made thus far, even though the gains are not consistent throughout the region. Despite these positive developments, the pace and composition of economic growth across ASEAN countries differ substantially, leading to uneven environmental consequences among member states. Countries with more advanced industrial bases and higher levels of energy consumption may experience disproportionately higher carbon emissions compared to less industrialized economies, even when overall economic growth rates appear similar. This divergence suggests that aggregate regional growth narratives may conceal important cross-country differences in how economic expansion translates into environmental pressure.

Table 1. Poverty Reduction, Peace and Stability, Food and Nutritional Security, Education, Women Empowerment, Employment Generation, and Inclusiveness in ASEAN

Indicator	Brunei	Kamboja	Indonesia	Lao PDR	Malaysia	Myanmar	Vietnam	Thailand	Singapura	Filipina
Popilation (Million)	0.459	16.5	270.6	7.2	31.9	54	96.5	69.6	5.7	108.1
Poverty (%)	-	12.9	10	18	6	24.8	7	10	-	17
Urban Population (%)	78	24	56	36	77	31	37	51	100	47
Unemployment Rate (%)	9.2	1.1	4.3	0.6	3.4	1.6	1.9	0.7	3.8	2.5
GDP (USD Miliar)	13.5	27.1	1,119.20	18.2	364.7	76.1	281.9	543.6	372.1	376.8
GDP per Kapita (USD)	28,000	1,643	4,136	2,515	11,415	1,408	2,914	7,808	65,233	3,485
GDP Growth (%)	4	7	5	5	4	3	7	2	0	6
Trade (USD Miliar)	-3	6	4	3	3	2	210	110	319	96
Import (USD Miliar)	10.9	12.4	171.5	6.8	123	20	271.4	274.9	541.8	151.7
Eksport (USD Miliar)	6.8	16.9	208	5.2	210.8	23.1	279.7	324.8	645.6	106.8
FDI Inflow (USD Miliar)	7.8	16.5	24.9	0.6	7.7	2.3	16.1	6.1	105.5	7.7
Domestic Investment (% GDP)	2.8	13.5	2.2	31	2.1	3	28.2	25	27	27

Source: ASEAN State of Climate Change Report, 2021

Table 1 presents key socio-economic indicators across ASEAN countries, including population size, poverty rates, urbanization, unemployment, GDP, GDP per capita, trade volumes, and foreign direct investment. Figure 1 analyzes that significant differences exist amongst ASEAN economies when compared in terms of economic size, development paths, and demographic composition. Singapore and Brunei

represent highly urbanized and high-income economies, whereas Indonesia and the Philippines dominate in terms of population size. On the other hand, structural development issues still plague Cambodia, Lao PDR, and Myanmar, as seen by their low per capita incomes and comparatively high rates of poverty (Quang & Thao, 2025; Susilowati et al., 2023). According to macroeconomic data, Singapore has the greatest GDP per capita, indicating advanced economic maturity, whereas Indonesia has the largest economy in the ASEAN region (Yang et al., 2025). Growth dynamics also show a dual trend: mature economies such as Brunei and Malaysia tend to experience more stable GDP growth supported by industrial diversification and foreign investment inflows, while emerging economies like Vietnam, Cambodia, and the Philippines continue to rely heavily on industrial expansion and trade openness to drive economic growth (Suhartoko & Ekaristi, 2023; Barbara & Widyawati, 2025). These pronounced cross-country differences suggest that the relationship between economic growth and environmental outcomes is unlikely to be uniform across ASEAN member states. In particular, variations in industrial structure, income levels, and energy use intensity may condition how GDP growth and industrial expansion translate into carbon emissions. This heterogeneity underscores the importance of adopting an empirical framework that captures both cross-sectional differences and temporal dynamics when analyzing the growth–emissions nexus in the ASEAN region.

Based on this explanation, it is necessary to study the influence of GDP and industrial growth on carbon emissions in ASEAN. To strengthen medium- and long-term climate ambition in the ASEAN region, member countries must establish clear policy directions by prioritizing green recovery strategies. The relationship between environmental quality and economic growth is commonly explained by the inverted U-shaped Environmental Kuznets Curve (EKC), which suggests that environmental degradation initially increases with economic growth before declining after a certain income threshold is reached (Antari et al., 2025; Qurrota A'yun & Khasanah, 2025). The EKC framework identifies three stages of development: pre-industrial, industrial, and post-industrial. During the transition from agriculture to industry, environmental degradation intensifies due to mass production, increased energy consumption, and rising demand (Discover Sustainability, 2025). However, as economies shift toward service-based and technology-driven structures, environmental awareness improves, investments in cleaner technologies increase, and demand for environmentally friendly goods and services grows (Yang et al., 2025). Although the EKC provides a useful theoretical lens, empirical evidence on its applicability in ASEAN remains mixed, particularly given the region's diverse development stages and industrial structures. Moreover, many existing studies rely on linear specifications that do not explicitly account for how industrial expansion may condition the environmental impact of economic growth. As a result, it remains unclear whether industrial growth merely acts as an additional source of emissions or whether it amplifies the effect of GDP growth on carbon emissions in developing regional contexts such as ASEAN.

Currently, rapid economic growth accompanied by industrial expansion has intensified air pollution and carbon emissions across ASEAN countries, contributing to global warming and environmental degradation (Quang & Thao, 2025). Industrial activities generate significant volumes of greenhouse gases and waste, which deteriorate air quality and environmental health (Barbara & Widyawati, 2025). Empirical studies confirm that GDP growth, industrialization, foreign direct investment, and energy consumption remain key drivers of carbon emissions in the ASEAN region (Suhartoko & Ekaristi, 2023; Fanny Sazuli, 2025). At the same time, public concern about climate change is increasing across Southeast Asia, where climate change is widely perceived as a serious and immediate threat to national well-being (Susilowati et al., 2023). Therefore, examining the influence of GDP and industrial growth on carbon emissions in ASEAN is essential to support evidence-based policy formulation and sustainable development strategies. Despite the growing volume of empirical research on emissions in ASEAN, existing studies have largely focused on identifying direct effects, providing limited insight into how economic growth and industrial expansion jointly shape environmental outcomes. This gap is particularly important in a regional context where industrial activity constitutes a major engine of economic growth, potentially reinforcing the environmental impact of GDP expansion. Accordingly, this study seeks to move beyond confirmation of established relationships by examining the interaction between economic growth and industrial growth, thereby offering a more integrated understanding of the growth–environment nexus in ASEAN countries.

Based on the above background, this study examines the effects of GDP and industrial growth, as well as their interaction, on carbon emission levels in ASEAN countries during the period 2010–2020. Taken together, these questions aim to move beyond identifying direct effects by examining whether industrial expansion conditions the environmental impact of economic growth in ASEAN countries.

METHOD

Economic growth is a central objective for ASEAN countries as they pursue improved standards of living and socio-economic development. Gross Domestic Product (GDP) is widely used as a key indicator of economic performance, capturing the total value of goods and services produced within an economy. An increase in GDP typically reflects expanded economic activity across sectors such as industry, trade, and services (Shahbaz et al., 2024). However, this growth often goes hand in hand with environmental pressures, particularly increased carbon dioxide (CO_2) emissions. In emerging and developing ASEAN economies, industrialization remains a major driver of GDP growth. Expanding industrial activity usually requires substantial energy inputs, much of which is sourced from fossil fuels such as coal, oil, and natural gas. These energy sources are among the primary contributors to CO_2 emissions (Nguyen & Vo, 2025). Therefore, countries experiencing rapid industrial expansion tend to exhibit

higher CO_2 emissions, establishing a positive relationship between GDP growth and environmental degradation (Rahman et al., 2024).

Industrial growth itself serves as a direct determinant of emission levels. Relative to service-based sectors, manufacturing and heavy industries are inherently more energy intensive and pollutive. Industrial processes emit greenhouse gases through fuel combustion, chemical reactions, and supporting logistics operations, including transportation and machinery use (Tran et al., 2025). As a result, increases in industrial output are expected to significantly contribute to rising carbon emissions in ASEAN economies, especially where environmental regulations and clean technologies are still underdeveloped (Wang & Chan, 2025). This relationship can be theoretically framed using the Environmental Kuznets Curve (EKC) hypothesis. According to the EKC, environmental degradation initially increases during early stages of economic growth due to industrial expansion and energy consumption. However, at higher income levels, societies begin to demand improved environmental quality, adopt cleaner technologies, and enforce stricter environmental regulations, ultimately leading to a reduction in emissions (Iqbal et al., 2025). In the ASEAN context, many countries remain in the rising phase of the EKC, where economic and industrial growth continues to drive higher emissions before a turning point toward sustainability can be reached. Based on the above reasoning, this study conceptualizes carbon dioxide emissions (Y) as the dependent variable, with GDP (X_1) and industrial growth (X_3) as key independent variables expected to exert positive influences on emissions. This framework provides a foundation for empirically examining how economic expansion and structural transformation affect environmental outcomes in the ASEAN region.

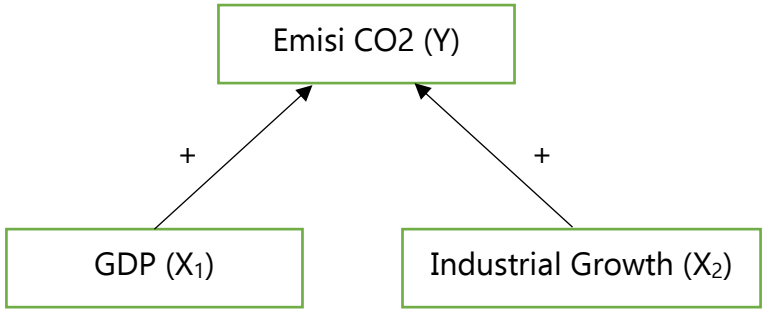

Figure 1. Mind Map Framework
Source: Researcher's Compilation, 2025

Based on Figure 1, this study adopts a quantitative research design to examine the influence of macroeconomic variables, namely Gross Domestic Product (GDP) and industrial growth (IND), on carbon emissions. The analysis employs secondary panel data obtained from the World Bank and covers nine ASEAN countries—Indonesia, Brunei Darussalam, the Philippines, Cambodia, Malaysia, Singapore, Myanmar, Thailand, and Vietnam—over the period 2010–2020. Gross Domestic Product and industrial growth are specified as the independent variables, while carbon emissions

serve as the dependent variable. Panel regression techniques are applied to analyze the relationships among these variables across countries and over time.

Table 2. Operational Definition of Variables

Variable	Technical Definition	Measurement	Data Source
Carbon Dioxide Emissions (CO_2)	Carbon dioxide emissions refer to waste gases released into the atmosphere as a result of fuel combustion, including gasoline, diesel, coal, natural gas, wood, and other hydrocarbon-based fuels. These emissions are a major contributor to air pollution and climate change.	Metric tons per capita (or total CO_2 emissions in metric tons, depending on model specification)	World Bank World Development Indicators (WDI)
Gross Domestic Product (GDP)	Gross Domestic Product is the total value of all final goods and services produced by residents of a country within a specific period, measured at constant prices to eliminate the effect of inflation. In this study, GDP is expressed in constant United States Dollars (base year 2000).	GDP at constant prices (US$), often transformed into natural logarithm	World Bank World Development Indicators (WDI)
Industry Growth (IND)	Industry growth represents the annual growth rate of industrial value added, defined as the net output of the industrial sector after subtracting intermediate inputs from total output. The data are measured at constant prices to ensure comparability over time.	Annual growth rate of industrial value added (%) at constant 2010 US$	World Bank World Development Indicators (WDI)

Source: Researcher's Compilation, 2025

This study employs panel data regression analysis, which combines cross-sectional data (several ASEAN countries) and time-series data (observations over multiple years). Panel data analysis is particularly suitable for this research because it allows the study to capture both differences across countries and changes over time in carbon dioxide emissions, economic growth, and industrial development.The use of panel data offers several important advantages. First, it enables the control of unobserved heterogeneity among countries. ASEAN countries differ in institutional quality, energy structure, climate policy, and technological development—factors that are difficult to observe or measure directly. Panel data models, especially the Fixed Effects Model (FEM), help control for these time-invariant characteristics, reducing omitted variable bias and improving the accuracy of estimated coefficients. Second, panel data increases the number of observations, which enhances the degrees of freedom and improves estimation efficiency. This is particularly relevant in environmental and macroeconomic studies, where data availability for individual countries may be limited. By combining cross-sectional and time-series dimensions, panel data provides more robust and reliable statistical inference.

Third, panel data analysis allows researchers to better examine dynamic relationships between variables. The relationship between GDP, industrial growth, and carbon emissions is not static but evolves over time as economies undergo structural transformation. Panel data regression makes it possible to observe how changes in GDP and industrial growth affect emissions across different countries and time periods,

which aligns closely with the Environmental Kuznets Curve (EKC) framework used in this study.

To estimate the panel regression model, three commonly used approaches are considered: the Common Effects Model (CEM), the Fixed Effects Model (FEM), and the Random Effects Model (REM). The Common Effects Model assumes homogeneity across countries and time, ignoring individual country effects. In contrast, the Fixed Effects Model allows for country-specific intercepts, capturing unobservable characteristics that remain constant over time. The Random Effects Model treats individual effects as random variables, assuming they are uncorrelated with the explanatory variables. Given the structural and economic diversity among ASEAN countries, this study expects that unobserved country-specific factors play a significant role in influencing carbon emissions. Although FEM and REM are initially considered appropriate given cross-country heterogeneity, formal specification tests ultimately guide the final model selection. To determine the most suitable model, formal specification tests such as the Chow test, Hausman test, and Lagrange Multiplier test are employed. Panel data regression is an appropriate and effective analytical method for this study because it accommodates cross-country heterogeneity, captures temporal dynamics, and provides robust empirical evidence on the impact of GDP and industrial growth on carbon emissions in the ASEAN region. The regression model in this study is as follows:

$$\boldsymbol{CO2_{it} = \beta_0 + \beta_1 GDP_{it} + \beta_2 IND_{it} + \varepsilon_{it}} \ldots\ldots\ldots\ldots\ldots\ldots (\mathbf{1})$$

Information:

$CO2_{it}$ = Carbon dioxide emissions (million tons of CO2)
GDP_{it} = GDP (Billion US$)
IND_{it} = Industrial Growth (Value added (% of GDP)
i = 1, 2, . . . n, indicates the number of cross-sections.
t = 1, 2, . . . t, indicates the time series dimension.
β_0 = (intercept).
β_1, β_2 = Coefficients of regression.
e = Error term.

Equation 1 represents the baseline specification examining the direct effects of economic growth and industrial growth on carbon emissions. To capture whether industrial expansion conditions the environmental impact of economic growth, Equation 2 extends the baseline model by incorporating an interaction term between GDP and industrial growth.

$$\boldsymbol{CO2_{it} = \beta_0 + \beta_1 GDP_{it} + \beta_2 IND_{it} + \beta_3 (GDP_{it} x IND_{it}) + \varepsilon_{it}} \ldots\ldots\ldots\ldots\ldots\ldots (\mathbf{2})$$

Ha (1): Gross Domestic Product has a positive and significant effect on the carbon emission in nine ASEAN countries from 2010 to 2020

Ha(2): Industrial Growth has a positive and significant effect on the carbon emission in nine ASEAN countries from 2010 to 2020

RESULT

The empirical analysis utilizes panel data covering nine ASEAN countries over the period 2010–2020. The dataset captures substantial cross-country and temporal variation in carbon dioxide emissions, reflecting differences in economic scale, levels of industrialization, and development trajectories within the region. This variation provides an appropriate empirical basis for panel regression analysis, allowing the study to examine how economic growth and industrial growth are associated with changes in carbon emissions across countries and over time.

Table 3. Descriptive Statistics

Variable	Obs	Mean	Minimum	Maximum	Std. Dev.
CO_2 Emissions (metric tons per capita)	126	4.215	0.32	10.84	2.971
GDP (constant US$)	126	4.76	0.12	12.10	3.85
Industrial Growth (%)	126	4.86	-3.45	12.73	2.91

Source: Researcher's Compilation, 2025

Table 3 reports the descriptive statistics of the variables employed in the analysis. Carbon dioxide emissions exhibit considerable dispersion across the sample, as indicated by a relatively large standard deviation, suggesting substantial heterogeneity among ASEAN countries. Gross Domestic Product also shows wide variation, reflecting pronounced differences in economic size and development levels within the region. Industrial growth records a positive mean value over the study period, indicating sustained industrial expansion, although negative minimum values point to periods of industrial slowdown or contraction in certain economies.

The average level of CO_2 emissions is 4.215 metric tons per capita, indicating that ASEAN economies remain significantly dependent on fossil-fuel-based energy consumption. The relatively high standard deviation (2.971) reflects substantial variation in emission intensity across countries, consistent with structural differences within the region. High-income economies such as Singapore and Brunei tend to record higher emission levels, whereas Cambodia and Myanmar exhibit relatively low emissions due to smaller industrial bases. Gross Domestic Product also displays a wide dispersion, ranging from approximately US$12 billion in smaller economies to over US$1.2 trillion in the largest economy, confirming strong economic disparities among ASEAN member states. Industrial growth averages 4.86 percent per year, indicating stable expansion of the industrial sector during the study period; negative values, with a minimum of –3.45 percent, reflect periods of contraction likely associated with external economic shocks, while the maximum growth rate of 12.73 percent points to episodes of rapid industrial expansion in several countries.

Table 4. Correlation Matrix

Variable	CO_2	GDP	IND
CO_2	1.000	0.684	0.592
GDP	0.684	1.000	0.611

Notes: CO_2 = carbon dioxide emissions; GDP = Gross Domestic Product; IND = industrial growth.

The correlation matrix reported in Table 4 indicates positive associations among carbon dioxide emissions, economic growth, and industrial growth. Carbon emissions are positively correlated with GDP, suggesting that higher levels of economic activity tend to be accompanied by increased emissions. Industrial growth also shows a positive correlation with carbon emissions, reflecting the energy-intensive nature of industrial production. Importantly, the correlation coefficients among the explanatory variables remain below commonly accepted multicollinearity thresholds, indicating that GDP and industrial growth can be jointly included in the regression models without raising serious collinearity concerns.

Prior to estimating the regression models, several panel specification tests were conducted to determine the most appropriate estimation approach. The Chow test was first applied to compare the Common Effect Model (CEM) and the Fixed Effect Model (FEM). The results indicate that the null hypothesis cannot be rejected, suggesting that the Common Effect Model is preferable. The Hausman test was then employed to compare the Fixed Effect Model and the Random Effect Model, and the results show that the Random Effect Model does not provide a statistically superior specification. Finally, the Lagrange Multiplier (LM) test was used to examine the presence of random effects, and the results indicate that neither individual nor time-specific effects are statistically significant. Taken together, these test results support the selection of the Common Effect Model as the baseline estimation method.

Table 5. Panel Model Selection Tests

Test	Statistic	Probability
CHOW Cross-section F	1.214	0.294
HAUSMAN Cross-section random	1.876	0.391
LM Breusch–Pagan	0.842	0.359

Table 5 reports the estimation results of the baseline panel regression model specified in Equation (1), which examines the direct effects of economic growth and industrial growth on carbon emissions. The results indicate that Gross Domestic Product (GDP) has a positive and statistically significant effect on carbon dioxide emissions, suggesting that higher levels of economic activity are associated with increased emissions. Industrial growth also exhibits a positive and statistically significant coefficient, indicating that expansion in the industrial sector contributes directly to rising carbon emissions across ASEAN countries. Overall, the baseline results confirm that both economic growth and industrial expansion are important drivers of environmental pressure in the region.

Table 6. Baseline Panel Regression Results (CEM)
(Dependent variable: CO_2 emissions)

Variable	Coefficient	Std. Error	t-Statistic	Probability
Constant	0.842	0.317	2.655	0.009
GDP	0.273	0.062	4.403	0.000

Variable	Coefficient	Std. Error	t-Statistic	Probability
IND	0.198	0.057	3.474	0.001
R^2	0.521			
Adjusted R^2	0.507			
F-statistic	36.12			0.000
Durbin–Watson	1.89			

Notes: GDP = Gross Domestic Product; IND = industrial growth. The model is estimated using the Common Effect Model (CEM)

Table 6 presents the estimation results of the extended model specified in Equation (2), which incorporates the interaction term between Gross Domestic Product (GDP) and industrial growth (IND). The coefficients of GDP and industrial growth remain positive and statistically significant, consistent with the baseline model. Importantly, the interaction term between GDP and industrial growth is also positive and statistically significant, indicating that the effect of economic growth on carbon emissions is conditioned by the level of industrial expansion. This result suggests that increases in GDP are associated with disproportionately higher carbon emissions in economies experiencing more rapid industrial growth.

Table 7. Panel Regression Results with Interaction Term (CEM)
(Dependent variable: CO_2 emissions)

Variable	Coefficient	Std. Error	t-Statistic	Probability
Constant	0.764	0.308	2.480	0.015
GDP	0.214	0.071	3.014	0.003
IND	0.162	0.061	2.656	0.009
GDP × IND	0.087	0.034	2.559	0.012
R^2	0.567			
Adjusted R^2	0.549			
F-statistic	31.48			0.000
Durbin–Watson	1.92			

Notes: GDP = Gross Domestic Product; IND = industrial growth

The interaction term (GDP × IND) captures whether industrial expansion conditions the impact of economic growth on carbon emissions. The model is estimated using the Common Effect Model (CEM).

The positive and statistically significant coefficient of the interaction term indicates that the marginal effect of economic growth on carbon emissions increases with higher levels of industrial growth. This finding implies that the impact of GDP on emissions is not constant across ASEAN countries, but varies according to the degree of industrial expansion. In economies where industrial growth is relatively strong, additional economic growth tends to be associated with a larger increase in carbon emissions compared to economies with lower industrial growth. Conversely, in countries experiencing slower industrial expansion, the emission response to economic growth appears more moderate. This pattern highlights the importance of accounting for industrial structure when assessing the environmental consequences of economic growth within the ASEAN region.

Overall, the empirical results demonstrate that economic growth and industrial growth are both positively associated with carbon emissions in ASEAN countries, and that their

effects are not independent. The baseline model confirms the direct contributions of GDP and industrial expansion to higher emission levels, while the extended model reveals a significant interaction effect between the two variables. This interaction indicates that the environmental impact of economic growth intensifies in the presence of stronger industrial expansion. Taken together, these findings provide a coherent empirical basis for further discussion on the mechanisms underlying the growth–emissions relationship and its implications for sustainable development in the ASEAN region.

DISCUSSION

The empirical findings confirm that economic growth is positively associated with carbon emissions in ASEAN countries, indicating that increases in GDP continue to be accompanied by rising environmental pressure. This result is consistent with the scale effect argument in environmental economics, which suggests that expanding economic activity increases energy consumption and resource use, thereby generating higher emissions, particularly in developing and emerging economies (Peter et al., 2016; Kabir et al., 2023). In the ASEAN context, where economic growth remains strongly supported by energy-intensive sectors, this positive relationship reflects the persistence of fossil-fuel-based production systems and limited decoupling between growth and environmental impact. Similar findings have been reported in previous studies focusing on ASEAN and comparable developing regions, which show that GDP growth remains a dominant driver of CO_2 emissions when technological progress and environmental regulation have not yet reached levels sufficient to offset scale effects (Suhartoko & Ekaristi, 2023; Rahman et al., 2024; Zafarullah & Mehnaz, 2025). Thus, the results suggest that, during the study period, economic expansion in ASEAN largely occurred within a development phase where growth-enhancing benefits have not yet been accompanied by proportional improvements in environmental efficiency.

Beyond aggregate economic growth, the positive and significant effect of industrial growth on carbon emissions underscores the structural dimension of environmental pressure in ASEAN economies. Manufacturing and heavy industries are inherently energy-intensive and rely heavily on fossil fuels, leading to higher emission intensity compared to service-based activities. This finding aligns with the structural effect emphasized in the Environmental Kuznets Curve (EKC) framework, where early and middle stages of development are characterized by industrial expansion that exacerbates environmental degradation before cleaner technologies and stricter regulations emerge (Iqbal et al., 2025). Empirical evidence from ASEAN and other developing regions similarly indicates that industrial growth remains a key determinant of rising CO_2 emissions when environmental governance and technological adoption lag behind production expansion (Nguyen & Vo, 2025; Wang & Chan, 2025). In line with previous studies, the results suggest that many ASEAN countries are still positioned on the upward-sloping segment of the EKC, where

industrialization-driven growth continues to intensify emissions rather than mitigate them (Antari et al., 2025; Qurrota A'yun & Khasanah, 2025). Consequently, the findings reinforce the argument that structural transformation toward less carbon-intensive activities has not yet been sufficient to offset the environmental costs of industrial expansion in the region.

The significant interaction effect between economic growth and industrial growth provides deeper insight into the growth–emissions nexus in ASEAN countries. This finding indicates that the environmental impact of GDP growth is not uniform, but rather depends on the extent of industrial expansion within an economy. In line with interaction-based interpretations of the EKC and structural transformation theories, economic growth tends to generate disproportionately higher carbon emissions in countries where industrial activity constitutes a dominant share of output and relies heavily on fossil-fuel-based energy (Antari et al., 2025; Iqbal et al., 2025). This result extends previous empirical studies that primarily examined the direct effects of GDP or industrialization in isolation, by demonstrating that industrial growth can amplify the scale effect of economic expansion on emissions (Suhartoko & Ekaristi, 2023; Rahman et al., 2024). In the ASEAN context, where industrial development remains a central engine of growth, the interaction effect suggests that structural characteristics of the economy play a critical role in shaping environmental outcomes. Similar patterns have been observed in studies of developing regions, which highlight that without substantial improvements in energy efficiency, technological upgrading, and environmental regulation, economic growth reinforced by industrial expansion is likely to intensify environmental degradation rather than alleviate it (Nguyen & Vo, 2025; Wang & Chan, 2025). Consequently, the interaction results emphasize that analyses focusing solely on average growth effects may underestimate the environmental consequences of growth in highly industrialized developing economies.

While the findings indicate a robust positive relationship between economic growth, industrial growth, and carbon emissions, they also help explain why prior empirical studies have reported mixed evidence regarding the growth–environment nexus in developing regions. Some studies document weaker or insignificant effects of GDP on emissions, often attributing these outcomes to improvements in technology, energy efficiency, or environmental regulation at higher income levels (Kabir et al., 2023; Yang et al., 2025). However, such results typically emerge in contexts where structural transformation toward service-oriented activities and cleaner production has progressed further. In contrast, the present findings suggest that in ASEAN—where industrialization remains a central driver of growth—the structural and scale effects continue to dominate potential efficiency gains. This helps reconcile inconsistencies in the literature by highlighting that the impact of economic growth on emissions is conditional on industrial structure, rather than universally linear or uniform across countries. Similar conclusions have been drawn in recent studies emphasizing context-dependent EKC dynamics, where the turning point toward environmental improvement is delayed in economies with prolonged reliance on energy-intensive

industries (Antari et al., 2025; Qurrota A'yun & Khasanah, 2025). Thus, the results contribute to the literature by clarifying that divergent empirical findings may reflect differences in structural composition and stages of development, rather than contradictions in the underlying growth–environment relationship.

Taken together, the findings of this study underscore the importance of integrating scale, structural, and interaction effects when examining the relationship between economic growth and environmental outcomes in developing regions. The positive effects of GDP and industrial growth on carbon emissions, combined with the significant interaction between the two, suggest that economic expansion in ASEAN has largely proceeded within a development trajectory where industrialization amplifies environmental pressure rather than mitigates it. These results reinforce the view that the EKC framework should be interpreted as context-dependent, with the transition toward lower emissions contingent upon structural transformation, technological upgrading, and institutional capacity (Iqbal et al., 2025; Antari et al., 2025). By explicitly demonstrating that industrial growth conditions the environmental impact of GDP growth, this study advances the existing literature beyond average-effect analyses and highlights the need to account for economic structure in growth–environment assessments. This conceptual synthesis provides a coherent foundation for discussing policy implications, particularly in relation to how ASEAN countries can reconcile continued economic development with the imperative of reducing carbon emissions amid ongoing industrial expansion (Kabir et al., 2023; Yang et al., 2025).

From a policy perspective, the results suggest that strategies aimed solely at sustaining economic growth in ASEAN are unlikely to reduce environmental pressure unless they are accompanied by structural and technological adjustments within the industrial sector. The positive interaction between GDP and industrial growth implies that policies promoting industrial expansion without parallel investments in energy efficiency, cleaner technologies, and environmental regulation may unintentionally intensify carbon emissions. This finding aligns with recent studies emphasizing that growth-oriented policies in developing regions must be complemented by targeted environmental and industrial policies to avoid locking economies into carbon-intensive development paths (Kabir et al., 2023; Nguyen & Vo, 2025). In the context of the EKC framework, the results indicate that reaching the turning point toward lower emissions requires deliberate policy intervention rather than reliance on income growth alone (Iqbal et al., 2025; Antari et al., 2025). For ASEAN countries, where industrialization remains a key driver of growth, this implies that environmental considerations need to be integrated into industrial development strategies, particularly through incentives for cleaner production, gradual energy transition, and strengthened regulatory capacity, in order to decouple economic growth from rising emissions over the long term.

CONCLUSION

This study examines the relationship between economic growth, industrial growth, and carbon emissions in ASEAN countries using panel data over the period 2010–2020, with particular emphasis on the interaction between economic and industrial expansion. The empirical results demonstrate that both GDP growth and industrial growth are positively associated with carbon emissions, confirming that economic expansion in the region continues to exert environmental pressure. More importantly, the significant interaction effect reveals that the impact of economic growth on emissions is amplified in economies experiencing stronger industrial expansion. These findings indicate that economic growth and industrialization in ASEAN are not environmentally neutral processes, but are closely intertwined in shaping emission outcomes. By moving beyond average-effect analyses and explicitly modeling the interaction between growth and industrial structure, this study provides a more nuanced understanding of the growth–environment nexus in a developing regional context.

From a theoretical perspective, this study contributes to the environmental economics literature by reinforcing the view that the relationship between economic growth and environmental degradation is highly context-dependent and shaped by structural characteristics of the economy. By incorporating an interaction term between economic growth and industrial growth, the analysis extends conventional EKC-based and average-effect approaches, demonstrating that industrial expansion can condition and intensify the environmental impact of GDP growth in developing regions. Empirically, the findings add to the limited body of recent evidence on ASEAN by providing updated panel-based results that capture cross-country heterogeneity and temporal dynamics within the region. In doing so, this study helps clarify why previous research has produced mixed results regarding the growth–emissions nexus, highlighting the importance of accounting for industrial structure when assessing the environmental consequences of economic development.

From a practical perspective, the findings imply that efforts to reduce carbon emissions in ASEAN should not rely solely on sustained economic growth, but must be accompanied by targeted policies that address the structure and environmental performance of the industrial sector. The interaction between economic growth and industrial expansion suggests that without improvements in energy efficiency, cleaner production technologies, and regulatory enforcement, continued industrial-led growth is likely to intensify environmental pressure. Accordingly, integrating environmental considerations into industrial development strategies is essential for achieving a more sustainable growth trajectory in the region. Finally, this study acknowledges certain limitations, including the focus on a limited set of macroeconomic variables and the use of a static panel framework. Future research could extend the analysis by incorporating additional determinants such as energy consumption, trade openness, or institutional quality, as well as by employing dynamic panel approaches to capture the persistence of carbon emissions over time.

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