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Manufacturing, Economic Growth, and Carbon Emissions in ASEAN: A Dynamic Story Unfolded through Panel VAR Analysis

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Abstract: This study examines the dynamic relationship between industrial CO_2 emissions, economic growth (EG), and manufacturing value added (MVA) in ten ASEAN countries during the period 2014 to 2023, employing a Panel Vector Autoregression (Panel VAR) approach and Granger causality tests. The estimation results indicate that all three variables exhibit strong short term persistence, with changes in each variable being predominantly influenced by its own historical values. Industrial CO_2 emissions display a high degree of inertia; however, their statistically significant impact on economic growth emerges only in the medium term. Economic growth has a significant effect on MVA, suggesting the existence of a structural linkage between the two sectors. In contrast, MVA does not appear to influence economic growth in the short run. This finding seems to contradict Kaldor's first law, although the internal dynamics of the manufacturing sector reflected in the significance of lags up to three previous periods support Verdoorn's perspective on endogenous growth mechanisms. The Granger causality tests confirm that only economic growth Granger-causes MVA, while CO_2 emissions do not exhibit any causal relationship with the other variables. These findings emphasize the importance of adopting a more adaptive policy approach in the medium to long term to integrate industrial and environmental agendas into the economic growth strategy of the ASEAN region.

Keywords: *CO2, Economic Growth, Manufacturing Value Added, Panel Vector Autoregression*

1. Introduction

Since the late 1980s, ASEAN countries have demonstrated impressive economic growth. This achievement is largely attributed to the implementation of sound economic policies and progressive regional cooperation, which together have created a conducive environment for the expansion of economic activities (Thambipillai, 1998). ASEAN's strategic geographic position between two major economic powers, China and India present both substantial opportunities and significant challenges in navigating the constantly evolving landscape of the global economy (Vu, 2020).

In this context, the issue of sustainable economic growth in the ASEAN region has become increasingly relevant, particularly in relation to the role of strategic sectors such as manufacturing. The economic transformation from traditional sectors to manufacturing not only reflects technological advancement and modernization but also serves as a critical indicator of the region's readiness to compete in the global economy.

A substantial body of literature highlights manufacturing as a key driver of economic growth and a fundamental pillar for effective industrialization (Anyanwu, 2017; Naudé & Szirmai,

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2011). Su & Yao (2017) further emphasize that industrialization is the most important engine of economic growth. Countries that have successfully achieved sustainable growth typically invest heavily in this sector (Anyanwu, 2018).

Moreover, the manufacturing sector contributes not only to increases in national output but also stimulates the growth of other sectors through both backward and forward linkages (Almosabbeh & Almoree, 2018). Productivity growth within manufacturing is positively associated with output expansion in the sector, as articulated in Verdoorn's Law (Cantore et al., 2017). In addition, manufacturing development encourages technological accumulation and enhances incentives to save, ultimately accelerating economic growth (Su & Yao, 2017).

However, it is important to note that the industrialization process in ASEAN has not been without environmental consequences. Behind the impressive growth achievements lies a significant environmental impact, particularly related to increased carbon emissions resulting from intensive fossil fuel consumption. The expansion of the manufacturing industry has driven massive energy consumption, which directly contributes to rising carbon emissions (Gutowski et al., 2013; Magazzino, 2014; Wenju & Zheng, 2018). In this regard, several studies have identified a relationship between economic growth and environmental degradation that resembles the Environmental Kuznets Curve (EKC). This curve suggests that environmental degradation initially rises with economic growth but begins to decline after reaching a certain income threshold, as cleaner technologies are adopted and more effective environmental policies are implemented (Hasbi, 2024; Othman et al., 2024; Ponce & Manlangit, 2023; Shahzad & Yasmin, 2016).

The above discussion reveals a close interconnection among the manufacturing sector, economic growth, and carbon emissions. These three elements influence each other and form a complex development dynamic. On one hand, manufacturing acts as a driver of growth, while on the other hand, it contributes significantly to carbon emissions, which have implications for environmental sustainability. Previous studies have examined the relationship between manufacturing and economic growth (Almosabbeh & Almoree, 2018; Libanio, 2016), as well as the relationship between industrial activity and carbon emissions (Al-Mulali & Ozturk, 2015; Hamit-Haggar, 2012). However, there remains a lack of research that simultaneously and dynamically analyzes the interrelationships among manufacturing value added (MVA), economic growth, and carbon emissions within an integrated model, particularly in the context of ASEAN countries.

This study seeks to fill that gap by investigating the dynamic relationships among economic growth, the development of the manufacturing sector, and carbon emissions in ASEAN countries. It employs a Panel Vector Autoregression (Panel VAR) approach to simultaneously and dynamically capture the reciprocal interactions among the variables within a panel data framework. This approach is chosen for its ability to identify both short term and long-term relationships without requiring prior assumptions about which variables are endogenous or exogenous. The findings of this study are expected to offer policy insights for formulating

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development strategies that balance economic growth, industrial sector strengthening, and environmental sustainability in the ASEAN region.

2. Research Method

A. Data Sources and Types

This study utilizes secondary data for the period from 2014 to 2023. The research objects are ten ASEAN member countries, namely Indonesia, Cambodia, Brunei Darussalam, Malaysia, Laos, Myanmar, the Philippines, Thailand, Singapore, and Vietnam. The data were obtained from the World Development Indicators (WDI) database.

Tabel 1. Variable Description

Variable	Code	Deskription	Source
Carbon Emissions	CO2	Carbon dioxide (CO2) emissions from industrial processes (million metric tons of CO2e)	WDI
Manufacturing Value Added	MVA	Manufacturing, value added (% of GDP)	WDI
Economic Growth	EG	Annual growth rate of Gross Domestic Product (GDP) (%)	WDI

Table 2 presents the descriptive statistics for the three variables: CO_2 emissions, manufacturing value added, and economic growth. For the CO_2 emissions variable, the minimum value is recorded at 0.0968, while the maximum reaches 53.4234. The mean value is 16.34719, with a standard deviation of 16.58143.

Tabel 2. Descriptive Statistics

Variabel	Min	Max	mean	SD	n
CO2 Emission	0.0968	53.4234	16.34719	16.58143	100
Manufactur Value Adde	1.586759	27.5735	19.03119	6.960906	100
Economic Growth	-12.0164	9.690767	3.712453	4.049823	100

Manufacturing Value Added exhibits a narrower range, with a minimum value of 1.586759 and a maximum of 27.5735, along with a mean of 19.03119 and a standard deviation of 6.960906. The Economic Growth variable shows a minimum value of -12.0164 and a maximum of 9.690767, with an average of 3.712453 and a standard deviation of 4.049823. Overall, the data reflect considerable variation across all variables, with each variable displaying a generally positive average value.

B. Data Analysis Technique

This study employs the Panel Vector Autoregression (Panel VAR) approach. This technique combines the traditional VAR framework, which treats all variables in the system as

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endogenous, with panel data analysis that accounts for unobserved individual heterogeneity (Magazzino, 2014). The Panel VAR method offers the advantage of analyzing dynamic relationships among variables while considering individual or unit-specific differences that are often unaccounted for in other methods. The estimation procedures in this study consist of the following steps:

Panel Data Stationarity Test

In this study, panel unit root testing is conducted using the Fisher-ADF method developed by Maddala & Wu (1999). This method is chosen for its ability to accommodate a high degree of heterogeneity across panel units and its advantage in combining p-values from individual unit root tests across cross-sectional units. As a result, the test statistic follows a chi-square distribution with 2N degrees of freedom. The equation for this test is presented as follows:

$$\bar{\lambda} = -2\sum_{i=1}^{N} \log_e(p_i) \sim \chi^2_{2N(d.f.)} \quad \text{......................... (1)}$$

where p_i represents the p-value from the Augmented Dickey-Fuller (ADF) unit root test for unit i.

Optimal Lag Selection Test

The impact of economic activities—such as economic growth or the development of the manufacturing sector—on carbon emissions typically does not occur instantaneously, but rather with a certain delay or lag. Since economic theory often does not provide a definitive guideline regarding the appropriate lag length, an empirical approach is required to determine the optimal lag length in the analysis of dynamic relationships among variables (Agus Widarjono, 2013).

To determine the optimal lag, criteria proposed by Akaike (Akaike Information Criterion, AIC) and Schwarz (Schwarz Information Criterion, SIC) can be used, as follows:

$$LnAIC = \frac{2k}{n} + \ln\left(\frac{SSR}{n}\right) \quad \text{......................... (2)}$$

$$LnSIC = \frac{k}{n}\ln n + \ln\left(\frac{SSR}{n}\right) \quad \text{......................... (3)}$$

where SSR denotes the sum of squared residuals, k represents the number of estimated parameters, and n is the number of observations. The optimal lag length is selected based on the smallest AIC or SIC value, considering its absolute value (Agus Widarjono, 2013).

Cointegration Test

Following the panel unit root test results indicating that the variables in the model are non-stationary, the next step is to conduct a cointegration analysis to examine whether a long-run

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relationship exists among the variables. In this study, the Pedroni cointegration method is employed, as it allows for heterogeneity across individuals in the panel. In general, Pedroni utilizes the following regression model:

$$y_{it} = \alpha_i + \delta_i t + \beta_i X_{it} + e_{it} \quad \text{……………………… (4)}$$

Where X_{it} is an *m*-dimensional column vector for each cross-sectional unit *i*, and βi is an *m*-dimensional row vector for each unit *i* in the panel.

Granger Causality Test

After conducting the cointegration test to identify the presence of long-run relationships among the variables, the next step is to perform a Granger causality test to determine the direction and existence of short-run causal relationships among the variables in the model. This test is essential because, in a Vector Autoregression (VAR) system, all variables are treated as endogenous, and it is therefore necessary to identify which variables temporally influence others. The results of the Granger causality test provide important insights into the short-run dynamics of variable interactions and contribute to a deeper understanding of the causal mechanisms within the studied economic system.

3. Results and Discussions

Unit Root Test

Tabel 3. Unit Root Test

Variabel	Level		1st difference		2nd difference	
	t-stat	Prob	t-stat	Prob	t-stat	Prob
CO2	21.5797	0.3637	20.8558	0.4057	32.5020	0.0382**
MVA	11.6569	0.9274	39.4456	0.0059*	49.2241	0.0003*
PE	25.8640	0.1704	45.3320	0.0010*	48.2430	0.0004*

*, **, and ***Indicate 1%, 5%, and 10% level of significance respectively

Based on the stationarity test results, it was found that none of the variables were stationary at the level. However, after the first difference differentiation, two variables, namely Manufacturing Value Added (MVA) and Economic Growth (EG), exhibited stationarity, while the CO_2 Emissions variable remained non-stationary. Since the VAR model requires all variables to be stationary at the same level, a transformation was made to the second difference. The second-difference test results show that all variables have met the stationarity requirement.

Uji Lag Optimum

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The VAR model is highly sensitive to the number of lags used, making the determination of the optimal lag length a crucial step in model estimation.

Tabel 4. Optimal Lag Test

Lag	LogL	LR	FPE	AIC	SC	HQ
0	-372.0915	NA	658.5534	15.00366	15.11838	15.04735
1	-356.6378	28.43480	509.2350	14.74551	15.20440	14.92026
2	-339.9599	28.68596	376.2748	14.43840	15.24145	14.74420
3	-315.7027	38.81156*	206.6182*	13.82811*	14.97532*	14.26497*

* Indicates lag order selected by the criterion

In this study, the optimal lag selection was carried out using several criteria, namely the Likelihood Ratio (LR), Final Prediction Error (FPE), Akaike Information Criterion (AIC), Schwarz Information Criterion (SC), and Hannan-Quinn Information Criterion (HQIC). Based on the test results, all these criteria indicated that the optimal lag in this study is the third lag.

Cointegration Test

Tabel 5. Cointegration Test

Alternative hypothesis: common AR coefs. (within-dimension)				
	Statistic	Prob.	Weighted Statistic	Prob.
Panel v-Statistic	-0.199684	0.5791	-0.658693	0.7450
Panel rho-Statistic	1.307961	0.9046	0.978038	0.8360
Panel PP-Statistic	-0.120554	0.4520	-0.967166	0.1667
Panel ADF-Statistic	0.533941	0.7033	-0.734601	0.2313

Alternative hypothesis: individual AR coefs. (between-dimension)

Based on the results of the Pedroni cointegration test, there is no evidence of cointegration among the variables, indicating the absence of a long-term relationship within the VAR system. Therefore, this study will focus on analyzing short-term relationships and dynamic causal patterns among the variables within the Panel VAR framework.

VAR Model Estimation

Based on the estimation results of the VAR model applied to 10 ASEAN countries, the analysis reveals that the relationships among the variables—CO_2 emissions, economic growth (PE), and the manufacturing sector (MVA)—exhibit distinct dynamic characteristics, with varying impacts in the short and medium term. Changes in CO_2 emissions ($D(D(CO_2))$) are significantly influenced by past changes in emissions ($CO_2(-1)$), with a 1% level of significance. This indicates a persistent pattern in CO_2 emission dynamics, meaning that increases or decreases in emissions in the past continue to have prolonged effects into subsequent periods. However, the second and

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third lags of CO_2 emissions do not show significant influence, suggesting that the impact of past emissions diminishes over time.

In the case of economic growth (D(D(PE))), the estimation results show that current economic performance is strongly affected by past growth conditions. The first and second lag terms are significant at the 1% confidence level, indicating that short-term economic dynamics are largely driven by previous performance. This phenomenon reflects economic inertia, where economic changes do not immediately respond to new stimuli but are instead shaped by past influences. In line with this, (Afonasova, 2017) stated that the phenomenon of inertia in economic development hinders modern economic growth and emphasized that economic growth and inertia form a dialectical relationship that mutually influences one another. She also highlighted that inertia arises from various factors, including economic instability and geopolitical pressures, which may delay responses to structural changes in the economy.

In addition, CO_2 emissions at the third lag also have a significant effect on economic growth at the 5% confidence level. Although the impact of emissions on economic growth does not appear immediately in the short term, environmental changes such as emission fluctuations can influence economic activity over the medium-term horizon. However, the manufacturing sector (MVA) does not show a significant effect on economic growth. This finding appears to contradict Kaldor's first law, which posits that the manufacturing sector is the engine of economic growth. The result is inconsistent with the findings of Almosabbeh & Almoree (2018) and Cantore et al. (2017), who empirically confirmed the validity of Kaldor's first law. (Cantore et al., 2017) further emphasized that although Kaldor's first law holds empirically, not all increases in manufacturing value added automatically contribute to economic growth. The discrepancy in this study may arise from the focus on short-term relationships only, while the possibility of a long-term relationship cannot be ruled out.

Empirical findings indicate that, in the case of the manufacturing sector (D(D(MVA))), the lag coefficients are significant up to the third lag at the 1% confidence level, suggesting strong internal dynamics and historical dependence within this sector. This is in line with Verdoorn's view, as described by (Libanio, 2016), that there is a positive causal relationship between output and labor productivity in the manufacturing sector, driven by both static and dynamic economies of scale. Thus, the temporal dependence pattern identified in this analysis reflects an endogenous growth mechanism within the manufacturing sector. The influence of economic growth on the manufacturing sector is also observed at the first and third lags, although it is only significant at the 10% level. This suggests a weaker relationship, which may manifest more prominently over the long term.

Tabel 6. Estimation of Panel VAR

	Response to		
Response of	D(D(CO2))	D(D(PE))	D(D(MVA))
D(D(CO2(-1)))	-0.561529	-0.642743	0.121739

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	(0.18593)	(0.60547)	(0.11791)
	[-3.02004]*	[-1.06156]	[1.03252]
D(D(CO2(-2)))	-0.247355	-0.293993	0.121469
	(0.19721)	(0.64220)	(0.12506)
	[-1.25425]	[-0.45779]	[0.97131]
D(D(CO2(-3)))	-0.053547	-1.115818	0.072563
	(0.17301)	(0.56338)	(0.10971)
	[-0.30951]	[-1.98059]***	[0.66142]
D(D(EG(-1)))	-0.054862	-1.392004	-0.040981
	(0.04558)	(0.14841)	(0.02890)
	[-1.20373]	[-9.37916]*	[-1.41797]
D(D(EG(-2)))	-0.037322	-2.012720	0.007169
	(0.08415)	(0.27401)	(0.05336)
	[-0.44354]	[-7.34533]*	[0.13435]
D(D(EG(-3)))	-0.033253	-2.368760	0.165065
	(0.13611)	(0.44323)	(0.08631)
	[-0.24431]	[-5.34437]*	[1.91246]***
D(D(MVA(-1)))	0.243272	-0.499264	-0.574271
	(0.26754)	(0.87121)	(0.16965)
	[0.90930]	[-0.57307]	[-3.38499]*
D(D(MVA(-2)))	0.304436	0.626232	-0.669231
	(0.31283)	(1.01869)	(0.19837)
	[0.97317]	[0.61474]	[-3.37361]*
D(D(MVA(-3)))	0.159411	-0.386919	-0.602676
	(0.31933)	(1.03987)	(0.20250)
	[0.49920]	[-0.37208]	[-2.97622]*
C	-0.394067	-1.860572	0.182877
	(0.31060)	(1.01143)	(0.19696)
	[-1.26873]	[-1.83955]	[0.92851]
R-squared	0.285026	0.738916	0.495836
Adj. R-squared	0.124157	0.680173	0.382399

*p < 0.10, **p < 0.05, ***p < 0.01 indicate significance at the 10%, 5%, and 1% levels, respectively*

Overall, the VAR analysis results show that, in the short-run dynamics, each variable tends to be driven by persistence effects or dependence on past values. These findings reinforce the concept of economic inertia as discussed by Afonasova (2017), who emphasized the need for *"an effective mechanism for overcoming inertia in a recession phase of economic development."* In the context of ASEAN, the dependence on past dynamics and environmental factors such as CO_2 emissions suggests that policy responses to climate change and industrial transformation require more adaptive and sustainable medium- to long-term strategies.

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Granger Causality Test

The results of the Granger causality test, applied within a panel VAR model covering 10 ASEAN countries, indicate that economic growth (PE) has a significant effect on manufacturing value added (MVA), with an F-statistic of 6.21661 and a p-value of 0.0009. This suggests that changes in the rate of economic growth can influence the manufacturing value added in these countries.

Tabel 7. Granger Causality Test

Null Hypothesis:	Obs	F-Statistic	Prob.
MVA does not Granger Cause CO2	70	0.02837	0.9935
CO2 does not Granger Cause MVA		0.32553	0.8069
PE does not Granger Cause CO2	70	1.03359	0.3839
CO2 does not Granger Cause PE		0.47979	0.6975
PE does not Granger Cause MVA	70	6.21661	0.0009*
MVA does not Granger Cause PE		0.40591	0.7493

*Significant on 5%

On the other hand, the results of the Granger causality test show that CO_2 emissions generated by industrial activities do not have a significant causal relationship with either manufacturing value added (MVA) or economic growth (PE), as indicated by high p-values in both directions of the test. This suggests that industrial CO_2 emissions do not directly influence economic growth or manufacturing value added, despite the data encompassing countries with differing policies, levels of industrialization, and economic structures. Therefore, this finding indicates that other factors such as country-specific industrial policies or differences in technology and industrial practices play a more dominant role in shaping the relationship among these variables.

Discussion

The findings of this study indicate that the dynamics of economic development, the manufacturing sector, and CO_2 emissions in ASEAN are predominantly influenced by the internal characteristics of each variable in the short term. This reflects a strong persistence pattern, suggesting that changes in these variables require time and do not respond immediately to short-term fluctuations in other variables. Such dependency may also reflect the region's economic structure, which is still undergoing a transition toward integrating sustainability into its development strategies.

The limited causal relationship between CO_2 emissions and both economic growth and the manufacturing sector implies that environmental policies in the ASEAN region may not yet be sufficiently aligned with the main drivers of economic dynamics. On the other hand, the identified

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relationship between economic growth and the manufacturing sector supports the view that macroeconomic strengthening can stimulate real sector activity. Nevertheless, the integration of growth and sustainability remains a challenge particularly in the face of global pressure to reduce emissions and shift toward a green economy.

4. Conclusions

The analysis using the Panel VAR model across ten ASEAN countries reveals that the relationship between industrial CO_2 emissions, economic growth, and manufacturing value added (MVA) is primarily driven by the internal dynamics of each variable, with strong evidence of short-term persistence effects. This finding is supported by the Granger causality test, which identifies a unidirectional causal relationship from economic growth to MVA, while no significant causal links are found between CO_2 emissions and the other economic variables. These results suggest that the integration of industrial development, economic growth, and environmental concerns remains limited in the short term. Therefore, long-term policy interventions are needed to effectively harmonize these three dimensions in a sustainable manner within the ASEAN context.

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