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ECONOMIC STRUCTURE, ENERGY TRANSITION, AND CARBON EMISSIONS IN ASEAN MARITIME STATES : PANEL ARDL APPROACH

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Abstract

This study analyzes the factors influencing carbon emissions in five ASEAN maritime countries, namely Indonesia, Philippines, Thailand, Malaysia, and Vietnam, using the Panel Autoregressive Distributed Lag (P-ARDL) method with data from 1993 to 2023. The variables studied include economic growth, energy intensity, the share of renewable energy, and sector structure using the agriculture industry proxy. Long-term estimates show that GDP per capita growth, energy intensity, and sector structure have a significant positive effect on carbon emissions, while renewable energy has a negative but insignificant effect. In the short term, energy intensity is the most dominant factor increasing emissions, while economic growth, renewable energy, and sector structure have not shown a significant impact. Vietnam and Thailand are still in the early phase of the Environmental Kuznets Curve (EKC), while the Philippines and Malaysia are beginning to show decoupling through energy efficiency and the service sector. Indonesia shows an unstable transition pattern. These findings emphasize the need to improve energy efficiency and accelerate the clean energy transition in ASEAN maritime countries.

Keywords: Carbon emissions, GDP, Renewable energy, Energy intensity, Sector structure, Panel ARDL.

INTRODUCTION

Climate change is one of the most pressing global environmental issues of the 21st century. This phenomenon is characterized by an increase in the Earth's average temperature, changes in weather patterns, rising sea levels, and an increased frequency of extreme weather events (Forster et al., 2023). One of the main causes of climate change is the increase in carbon dioxide (CO_2) emissions resulting from human activities (Dengler & Reid, 2023), a particular challenge for developing countries, particularly in Southeast Asia (Lee & Romero, 2023), due to the growth of global emissions due to rapid industrialization and increasing consumption of fossil-based energy. This increase in CO_2 creates positive radiative forcing, an energy imbalance in the Earth's system that ultimately triggers global warming (Bennedsen et al., 2024; Friedlingstein et al., 2025). The concentration of CO_2 in the atmosphere has increased significantly year after year. Data shows a significant surge in global carbon emissions from 11.31 billion tons in 1965 to approximately 38.59 billion tons in 2024. Percentage-wise, carbon emissions have increased by more than 300% since 1965(Friedlingstein et al., 2025).

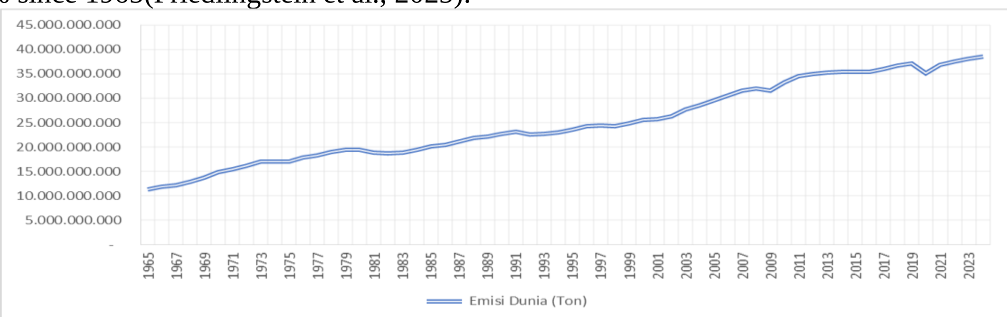

Figure 1 Global CO_2 Carbon Emissions (Tons)
Source : (Our World in data, 2024)

The issue of carbon emissions related to climate change has also become a trending topic in developing countries, such as ASEAN, which is predominantly a maritime nation facing the dual pressures of maintaining economic growth based on maritime trade while simultaneously curbing the degradation of coastal environments, the atmosphere, and marine ecosystems. However, there remains a gap between commitments to reducing emissions and policy implementation on the ground. Global warming has numerous effects, including drought, environmental degradation, sea level rise, forest fires, and climate change. Development processes that ignore environmental factors have led to significant environmental degradation, especially in developing countries (Adam & Pujiati, 2025). According to (UNTRAD, 2022), over 80% of global trade passes through sea lanes, making maritime nations a hub for carbon emissions from shipping and its supporting industries. However, emissions control policies in Southeast Asia's maritime sector lag behind those in Europe, creating a gap in carbon management in the maritime and coastal industries.

Indonesia, as the world's largest maritime nation with over 17,000 islands, relies heavily on maritime-based economic activities, industry, and maritime transportation. The national energy sector is still dominated by coal, which contributes over 60% of national electricity generation (Idroes et al., 2024; IEA, 2022). Meanwhile, Indonesia targets a renewable energy mix of 23% by 2025, but the actual figure has only reached around 13–14% (IEA, 2025). (Ahmad et al., 2024; Rum et al., 2024) proves that GDP per capita growth in Indonesia still has a significant positive correlation with carbon emissions. This finding confirms the imbalance between the orientation of maritime and industrial economic development and Indonesia's actual capacity to realize the transition to clean energy. As an archipelagic nation in the Western Pacific, the Philippines boasts a strong maritime economy driven by fisheries, maritime logistics, and international trade. It is also known as one of the world's largest geothermal energy users (IRENA, 2023; Koons, 2024). However, carbon emissions continue to rise in line with economic growth and coastal urbanization (Raihan, 2023). These findings indicate that renewable energy penetration in the Philippines has not fully offset the increase in emissions driven by surging electricity demand and industrial activity, creating a gap in the effectiveness of renewable energy as a tool to control environmental pressures in this maritime nation.

Vietnam is a maritime nation with a long coastline along the South China Sea and a hub for manufacturing and export trade in ASEAN. Its rapid economic growth over the past two decades has relied on energy-intensive industries and coal-fired power plants (BloombergNEF, 2023). Although Vietnam has been aggressively developing solar and wind energy since 2019, (Tachev, 2024) found that industrialization remains the dominant factor driving emissions increases. This reflects a structural imbalance between the rate of maritime industry expansion and the rapid adoption of clean energy as an emissions mitigation measure. Thailand, as a maritime nation in the Gulf of Thailand, boasts rapidly growing marine tourism, maritime transportation, and manufacturing industries. On the other hand, Thailand has made significant progress in energy efficiency development compared to other ASEAN countries. However, (Rajbhandari et al., 2024) found that per capita GDP growth still contributes significantly to CO_2 emissions. This finding indicates that improvements in energy efficiency have not fully offset the growing pressure from maritime and industrial activities on emissions. Malaysia is a maritime nation with the busiest international shipping lane in the Strait of Malacca, supporting trade and heavy industry. Its energy structure still relies on natural gas and petroleum, although solar energy development is gaining momentum. (Begum et al., 2015; Majekodunmi et al., 2023) state that Malaysia's economic growth continues to drive long-term increases in carbon emissions. The gap that arises is the maritime economic system's dependence on fossil fuels, which remains dominant compared to green energy policies.

According to the Environmental Kuznets Curve (EKC) theory (Grossman & Krueger, 1995), in the early stages of economic growth, increases in GDP tend to be followed by increases in environmental emissions. Later, according to (Osobajo et al., 2020), carbon emissions are a major factor causing climate change and causing significant economic losses. Overall, climate change will impact economic activity, particularly in sectors that are highly dependent on climate change. Energy intensity is an important indicator explaining differences in environmental performance between maritime countries. Indonesia and Vietnam are classified as countries with high energy intensity, while Thailand and Malaysia are relatively more efficient (IEA, 2024). In terms of economic sector structure, ASEAN maritime countries exhibit a shift from agriculture to industry and services based on maritime trade. (Vo et al., 2024) explain that the initial phase of industrialization typically increases emissions before reaching a point of technological efficiency. Indonesia and Vietnam remain heavily reliant on agro- and primary industries, while Malaysia and Thailand are more dominant in manufacturing and services. However, few studies have simultaneously examined the role of the agricultural and industrial sectors on carbon emissions in ASEAN maritime countries, creating strong empirical inequalities. A previous study (Pal et al., 2025) focused on energy consumption, economic growth, industrialization, and the human development index (HDI) on carbon emissions using the panel autoregressive distributed lag (ARDL) method. GDP and renewable energy use had a significant impact on short-term emissions, while industrialization and the HDI had minimal impact. Industrialization also has a positive long-term relationship with emissions, but it is not statistically significant over time, while an increase in the HDI by 1 unit increases emissions by 0.014%, which may indicate a trade-off between development and environmental sustainability, this study only focuses on several Asian countries. Then the study (Noor & Saputra, 2020) aims to investigate the existence of EKC and see the various relationships between carbon emissions and Gross Domestic Product (GDP) per capita in four middle-income countries in the ASEAN region. The study used annual data from 1971-2014 in Indonesia, Thailand, the Philippines, and Malaysia using a simultaneous two-stage least square (2SLS) model. The results of the analysis found that first, the existence of EKC cannot be validated in the four countries because energy and transportation policies in each country have not been able to reduce environmental degradation and second, the positive effect runs in one direction from carbon emissions to GDP in the four countries.

A study (Feriansyah & Larre, 2022) investigated the relationship between economic growth and CO2 emissions using the ARDL Panel method for eight ASEAN countries. This study found that GDP has a significant long-term impact on CO2 emissions in ASEAN countries, and then showed that GDP significantly impacts CO2 emissions in the short term for four countries: Indonesia, Malaysia, Thailand, and Cambodia. A study (Shahbaz et al., 2013) examined the relationship between economic growth, energy consumption, financial development, trade openness, and CO2 emissions in Indonesia using the ARDL method. Economic growth and energy consumption increase CO2 emissions, while financial development and trade openness reduce them.

Most previous studies in the ASEAN and Asia regions still use the panel approach, ARDL, and Panel ARDL, or only highlight the relationship between energy consumption, carbon emissions, and economic growth without simultaneously considering energy intensity and sectoral structure. However, the characteristics of maritime countries cause economic and energy adjustment processes to be gradual and dynamic. This limitation creates a methodological gap in understanding differences in short-term and long-term responses between countries. Based on these various phenomena, this study is important to comprehensively analyze the influence of economic growth, energy intensity, renewable energy share, and agricultural sector structure on carbon emissions in five ASEAN maritime countries using the ARDL Panel approach: Indonesia, the Philippines, Thailand, Malaysia, and Vietnam. The ARDL method is able to accommodate short-term and long-term dynamics simultaneously (Pesaran et al., 2001). The results of this study are expected to provide relevant empirical contributions to the formulation of energy transition policies and sustainable development based on the characteristics of maritime countries.

METHOD

This study uses a quantitative approach with an econometric Panel Autoregressive Distributed Lag (P-ARDL) model to analyze the short-term and long-term relationships between carbon emissions and economic-industry variables. The relationships analyzed in this study are economic growth, energy intensity, renewable energy share, and agricultural sector structure on carbon emissions from 1993-2023 in ASEAN maritime countries, namely Indonesia, the Philippines, Thailand, Malaysia, and Vietnam. Data collection is from the World Bank Indicator and our world in data.

Table 1. Variables and Data Sources

Variable	Definition	Symbol	Source	Reference
CO_2 Emissions per Capita (Tons per Capita)	Carbon emissions as a key indicator of the climate crisis	CO2	Our World in Data	(Pal et al., 2025)
GDP Growth per capita	Per capita economic growth	GDP	World Bank (WDI)	(Myszczyszyn & Supro´n, 2021)
Renewable Energy Share (%)	Share of renewable energy in total energy	RE	Our World in Data	(Yakymchuk & Maxand, 2025; Zheng et al., 2023)
Energy Intensity (MJ per USD GDP)	National energy intensity	EI	Our World in Data	(Begum et al., 2015; Yakymchuk & Maxand, 2025)
Agriculture Industry Share	Portion of agricultural industry in GDP	AI	Our World in Data	(Luo et al., 2024; Tagwi, 2022)

The basic model used is :

$$\Delta CO2_{it} = \alpha_i + \sum_{j=1}^{p1} \varphi_{ij} \Delta CO2_{i,t-j} + \sum_{j=0}^{q} \beta_{ij} \Delta X_{i,t-j} + \theta_i ECM_{i,t-1} + \varepsilon_{it}$$

$\Delta CO2_{it}$ Dependent variabel, change in carbon emissions for entity i at time t. $\sum_{j=1}^{p1} \varphi_{ij} \Delta CO2_{i,t-j}$ Lagged values of the dependent variable (carbon emissions). $\sum_{j=0}^{q} \beta_{ij} \Delta X_{i,t-j}$ Short-term dynamics of independent variables. These variables are denoted as Xi,t, which include:

$GDP_{i,t}$: Per Capita Economic Growth
$RE_{i,t}$: Renewable Energy
$EI_{i,t}$: Energy Intensity
$AI_{i,t}$: Agriculture Industry

$\theta_i ECM_{i,t-1}$ The Error Correction Term (ECM) at lag t−1 represents the long-term equilibrium relationship between variables, where the ECM measures the magnitude of the deviation of carbon emissions from the long-term equilibrium level. Coefficient θ_t In the ECM framework, this indicates a speed adjustment system returning to long-term equilibrium. ε_{it} The error term or residual represents all other factors that influence carbon emissions but are not captured in the model.

RESULTS AND DISCUSSION

RESULT

Stationarity Test

The stationarity test is conducted as a preliminary step to ensure that each variable has stable statistical properties, thereby avoiding the risk of pseudo-regression (spurious regression) that commonly occurs in non-stationary time series data. Using the Im, Pesaran & Shin (IPS) and Levin, Lin & Chu (LLC) tests, this study found that the variables carbon emissions, GDP per capita growth, renewable energy, energy intensity, and industrialization are integrated in a combination of orders I(0) and I(1).

Table 2.Stationary Test Results

Variable	CIPS		CLLC	
	I(0)	I(1)	I(0)	I(1)
CO2	0.9890	0.0000	0.4362	0.0000
GDP	10.000	0.0000	0.9996	0.0000
RE	0.9864	0.0000	0.9881	0.0000
EI	0.9843	0.0000	0.5851	0.0000
AI	0.1852	0.0000	0.0159	0.0000

Source: Processed data, Eviews

Pedroni Cointegration test

Based on the Pedroni Cointegration Test results in the table above, it can be seen that most of the strong cointegration statistics, particularly the Panel PP-statistic, Panel ADF-statistic, Group PP-statistic, and Group ADF-statistic, are significant at the 5% level. This indicates that the variables in the model have a long-term relationship and are moving towards a common equilibrium. Therefore, it can be concluded that cointegration exists in the analyzed panel data, allowing further analysis such as long-term and short-term model estimation.

Table 3.Pedroni Cointegration Test Results

Alternative hypothesis: common AR coefs (Within-dimension)				
	Statistic	Prob.	Statistic	Prob
Panel v-Statistic	-0.753951	0.7746	-0.722244	0.7649
Pane rho-Statistic	1.069.969	0.8577	0.045043	0.5180
Panel PP-Statistic	-3.417.138	0.0003	-2.940.556	0.0016
Panel ADF-Statistic	-3.755.611	0.0001	-3.521.144	0.0002

Alternative hypothesis: common AR coefs (Within-dimension)		
	Statistic	Prob.
Group rho-Statistic	0.868566	0.8075
Group PP-Statistic	-3.835.248	0.0001
Group ADF-Statistic	-3.614.136	0.0002

Source: Processed data, Eviews

Short and Long Term Model Estimation

The next step in this analysis is to estimate short- and long-term dynamics using the Panel Autoregressive Distributed Lag (P-ARDL) model. The ARDL Panel approach allows a clear separation between the short-run adjustment and long-run equilibrium effects of each independent variable on the dependent variable in each country. Short-run estimates depict the immediate response and temporary changes in carbon emissions when shocks occur to economic variables such as GDP growth, energy intensity, the Agriculture industry proxy for the structure sector, and renewable energy utilization. Meanwhile, long-run estimates emphasize stable equilibrium relationships between variables, argues reflect the fundamental tendencies of the economy over a longer period of time after the adjustment process is complete.

Table 4. Long-Term and Short-Term Estimation Results

Long Run Equation				
Variabel	Coeff	Std. Error	t-Statistik	Prob.
GDP	0.000181	2.58E-06	6.993.162	0.0000
RE	-0.005577	0.003244	-1.719.451	0.0923
EI	6.25E-05	2.01E-06	3.110.471	0.0000
AI	0.010344	0.002141	4.831.637	0.0000
Short Run Equation				
Variabel	Coeff	Std. Error	t-Statistik	Prob.
COINTEQ01	-0.734466	0.288330	-2.547.307	0.0143
D(CO2(-1))	0.076742	0.298717	0.256905	0.7984
D(CO2(-2))	0.054056	0.312955	0.172728	0.8636
D(CO2(-3))	-0.073083	0.140655	-0.519588	0.6058
D(GDP)	-3.26E-05	8.82E-05	-0.369897	0.7132
D(GDP(-1))	-9.08E-05	8.59E-05	-1.057.850	0.2956
D(GDP(-2))	-0.000173	0.000146	-1.185.360	0.2420
D(GDP(-3))	5.19E-05	5.01E-05	1.035.503	0.3058
D(RE)	-0.017082	0.043260	-0.394866	0.6948
D(RE(-1))	0.048464	0.080225	0.604107	0.5487
D(RE-2))	0.125729	0.135095	0.930672	0.3569
D(RE-3))	0.051476	0.071491	0.720037	0.4751
D(EI)	0.000132	2.71E-05	4.876.118	0.0000
D(EI(-1))	9.71E-05	4.74E-05	2.048.554	0.0462
D(EI(-2))	0.000105	7.99E-05	1.311.307	0.1963
D(EI(-3))	3.50E-05	6.22E-05	0.561684	0.5771
D(AI)	0.048140	0.052780	0.912088	0.3665
D(AI(-1))	0.039433	0.073654	0.535372	0.5950
D(AI(-2))	0.047835	0.072081	0.663631	0.5102
D(AI(-3))	-0.014175	0.027640	-0.512837	0.6105
C	1.454.790	0.972607	1.495.763	0.1415

Source: Processed data, Eviews

Short-Term Estimates for Each Country

Table 5. Short-Term Estimate Results for Each Country

Variable	Indonesia Coef. (prob)	Filipina Coef. (prob)	Vietnam Coef. (prob)	Thailand Coef. (prob)	Malaysia Coef. (prob)
COINTEQ01	-0.635998 (0,0002)	-0.305879 (0.0000)	-0.017044 (0.0378)	-1.056.494 (0.0000)	-1.656.913 (0.0143)
D(CO2(-1))	-0.239552 (0,0046)	-0.619104 (0.0000)	-0.248738 (0.0418)	0.429450 (0.0000)	1.061.653 (0.0036)
D(CO2(-2))	0.031764 (0.5141)	-0.255002 (0.0011)	-0.910432 (0.0001)	0.486370 (0.0000)	0.917580 (0.0136)
D(CO2(-3))	-0.052431 (0.3287)	-0.015329 (0.5314)	-0.423424 (0.0584)	-0.277851 (0.0000)	0.403621 (0.0032)
D(GDP)	1.28E-07 (0.0001)	-6.35E-05 (0.0000)	0.000282 (0.0000)	-0.000143 (0.0000)	-0.000238 (0.0000)
D(GDP(-1))	-0.000129 (0.0000)	-6.77E-05 (0.0000)	-0.000143 (0.0000)	0.000208 (0.0000)	-0.000322 (0.0000)
D(GDP(-2))	7.00E-05 (0.0000)	-6.95E-05 (0.0000)	-0.000743 (0.0000)	-6.57E-06 (0.0000)	-0.000116 (0.0000)
D(GDP(-3))	0.000111 (0.0000)	-4.14E-05 (0.0000)	0.000216 (0.0000)	2.56E-05 (0.0000)	-5.11E-05 (0.0000)
D(RE)	-0.002003 (0.0134)	-0.002698 (0.0000)	-0.011598 (0.0000)	-0.169376 (0.0000)	0.100266 (0.0156)
D(RE(-1))	0.054748 (0.0000)	-0.000117 (0.0000)	-0.019740 (0.0000)	-0.136663 (0.0000)	0.344094 (0.0016)
D(RE(-2))	0.070541 (0.0000)	0.010923 (0.0002)	0.011247 (0.0000)	-0.116232 (0.0000)	0.652167 (0.0001)
D(RE(-3))	0.011641 (0.0001)	0.001924 (0.0000)	0.008622 (0.0000)	-0.091684 (0.0000)	0.326878 (0.0012)
D(EI)	0.000125 (0.0001)	0.000187 (0.0000)	0.000183 (0.0000)	0.000126 (0.0000)	3.76E-05 (0.0000)
D(EI(-1))	0.000110 (0.0000)	0.000179 (0.0000)	0.000133 (0.0000)	-8.70E-05 (0.0000)	0.000151 (0.0000)
D(EI(-2))	-8.14E-05 (0.0000)	0.000118 (0.0000)	0.000397 (0.0000)	3.31E-05 (0.0000)	5.70E-05 (0.0000)
D(EI(-3))	-0.000185 (0.0000)	2.78E-05 (0.0000)	0.000193 (0.0000)	9.85E-05 (0.0000)	3.99E-05 (0.0000)
D(AI)	-0.015911 (0.0000)	0.002024 (0.0000)	0.016715 (0.0001)	-0.019761 (0.0000)	0.257633 (0.0010)
D(AI(-1))	-0.029270 (0.0000)	0.015896 (0.0000)	0.017761 (0.0001)	-0.123007 (0.0000)	0.315783 (0.0007)
D(AI(-2))	-0.010996 (0.0000)	-0.004245 (0.0000)	-0.047847 (0.0000)	-0.032232 (0.0000)	0.334494 (0.0001)
D(AI(-3))	-0.004212 (0.0001)	-0.004069 (0.0000)	-0.025443 (0.0000)	-0.104926 (0.0000)	0.067774 (0.0195)
C	0.483649 (0.0001)	0.114869 (0.0000)	-0.055496 (0.0004)	1.549.082 (0.0000)	5.181.846 (0.2026)

Source: Processed data, Eviews

DISCUSSION

Long-term estimation results show that GDP per capita and energy intensity have a positive and significant effect on carbon emissions. The very small but significant coefficient for GDP indicates that economic growth continues to drive increased emissions, consistent with the scale effect theory in the Environmental Kuznets Curve (EKC), which states that increased economic activity in the early stages of development leads to increased energy consumption and intensification of production processes, resulting in greater emissions. This finding is consistent with research (Ang, 2007; Shahbaz et al., 2013), which found that increased economic activity in developing countries typically increases emissions due to the dominance of fossil fuels and energy-intensive industrialization processes. Energy intensity is the most statistically dominant variable. Its large and highly significant coefficient indicates that the greater the energy use in generating economic output, the higher the CO_2 emissions. This explains that the five maritime ASEAN countries (categorized as developing) are currently at a development stage that requires high energy intensity, so industrialization processes, manufacturing sector expansion, and marine-based economic activities remain heavily dependent on fossil fuels. This dependency leads to an unavoidable increase in carbon emissions, especially when clean technology innovation capacity and renewable energy penetration are not yet sufficient to offset the growing energy demand. This is reinforced by findings (Sadorsky, 2014), which state that energy efficiency is a key factor in controlling emissions in developing countries. Furthermore, research (Zhang et al., 2023) shows that in Morocco, increasing energy intensity contributes significantly to the increase in CO2 emissions. Meanwhile, the share of renewable energy shows a negative coefficient, although not significant. This trend is consistent with the theory that increasing renewable energy tends to reduce emissions because it acts as a substitute for fossil fuels. The insignificance of these results can be explained by the limited capacity for clean technology innovation and the level of renewable energy penetration, which is still unable to optimally replace energy needs. These findings are consistent with previous studies (Justice et al., 2024; Mirziyoyeva & Salahodjaev, 2022), which prove that renewable energy has a negative effect.

The agriculture industry variable has a significant positive effect, meaning that the greater the role of energy-intensive industrial and agricultural sectors, the higher carbon emissions. This finding aligns with research (Balogh, 2022; Karimi Alavijeh et al., 2023), which shows that early industrialization, as proxied by the agriculture industry, in developing countries is associated with increased emissions due to inefficient technology. In the short term, the most significant variable is energy intensity, both at lag 0 and lag 1. This effect indicates that changes in energy consumption in production directly increase carbon emissions, even over very short periods. This is consistent with the theory of short-run energy-emission elasticity and is supported by research (Lean & Smyth, 2010), which found that ASEAN countries are highly sensitive to changes in energy intensity. Conversely, GDP (Espoir et al., 2023; Feriansyah & Larre, 2022), renewable energy, and industrial structure are insignificant, indicating that the impact of the economy and energy transition on emissions takes time to become apparent. This occurs because changes in renewable energy use and industrial sector restructuring typically take time to influence production patterns, energy consumption, and the technologies used. In practice, the adoption of clean energy technologies, increased energy efficiency, and shifts in the proportions of the industrial or agricultural sectors do not occur instantly, but rather through a gradual process involving adjustments in infrastructure, capital investment, and production behavior. This pattern is particularly common in developing countries and is supported by those who emphasize that the impacts of renewable energy emerge primarily over the long term.

The cointegration coefficient (COINTEQ01) in the short-run estimation is negative and significant (–0.734), indicating the presence of an error correction mechanism (ECM). This means that approximately 73% of deviations from the long-run equilibrium are corrected within a single period. This indicates relatively rapid adjustment, confirming the existence of a stable long-run relationship between the variables. The short-term estimation results for each country indicate that the effect of GDP per capita on carbon emissions is heterogeneous. Vietnam and Thailand exhibit positive and significant coefficients, indicating that economic growth remains correlated with increased emissions, consistent with the early phase of the Environmental Kuznets Curve (EKC). Conversely, the Philippines and Malaysia exhibit negative coefficients, indicating decoupling through energy efficiency, the dominance of the service sector, and the adoption of clean technologies. Indonesia exhibits varying results, reflecting the unstable state of its economic transition. These findings align with those of (Begum et al., 2015), which assert that the relationship between GDP and carbon emissions is largely determined by economic structure and energy efficiency levels.

For Indonesia and Vietnam, positive coefficients at several lags indicate that renewable energy has not yet fully replaced fossil fuels. Conversely, the Philippines and Thailand record negative and significant coefficients, indicating that renewable energy is effective in reducing emissions (Justice et al., 2024). Meanwhile, Malaysia exhibits a significant positive coefficient, likely due to the dominance of bioenergy, which still produces emissions. Furthermore, energy intensity shows high consistency, with positive and significant coefficients across almost all countries. This indicates that high energy consumption per unit of output drives increased carbon emissions, in line with findings (Sadorsky, 2014). The structure of the economic sector through the agricultural industry variable shows differences across countries. Indonesia and Thailand recorded negative trends, indicating that a shift towards more efficient sectors contributed to lower emissions. Conversely, the Philippines, Vietnam, and Malaysia showed significantly positive coefficients, indicating that the energy-intensive industrial and agricultural sectors remain major contributors to emissions.

CONCLUSION

This study confirms that ASEAN maritime nations face structural challenges in balancing industrial and maritime-based economic growth with carbon emission reduction obligations. The gap in literature analysis related to simultaneous economic growth, energy intensity, renewable energy share, and sectoral structure serves as an important basis for this research. Based on the analysis and discussion, this study concludes that the dynamics of carbon emissions in ASEAN maritime nations are significantly influenced by the economic and energy developments in each country. In the long term, the variables of GDP per capita growth, energy intensity, and the agricultural-industrial sector structure have been shown to have a positive and significant influence on increasing carbon emissions. Meanwhile, the share of renewable energy shows a negative influence, as theoretically suggested, but is not yet statistically significant. In the short term, energy intensity is the only variable showing a significant influence on carbon emissions, while GDP, renewable energy, and sectoral structure do not show a direct impact. Differences between countries are also clear, with Vietnam and Thailand still in the early stages of the Environmental Kuznets Curve (EKC), the Philippines and Malaysia showing a tendency toward decoupling through energy efficiency and service sector development, while Indonesia exhibits an unstable energy transition pattern due to its high dependence on fossil fuels.

Based on these findings, several policy imperatives need to be considered by ASEAN maritime countries. First, increasing energy efficiency needs to be a top priority through industrial technology modernization, implementing efficiency standards in the production sector, and providing incentives for the use of energy-efficient equipment. Second, accelerating the transition to renewable energy must be strengthened through investment in clean energy infrastructure, optimizing regulations such as feed-in tariffs, and expanding the integration of renewable energy into the national electricity system. Third, economic sector reconstruction is needed to reduce dependence on energy-intensive industries and encourage the growth of the service sector and low-carbon value-added industries. Fourth, the maritime sector, as the backbone of regional economic activity, needs to be directed toward reducing emissions through port electrification, strict monitoring of ship fuel use, and the implementation of environmentally friendly shipping standards. Fifth, synergy between economic and energy policies must be strengthened so that GDP growth does not automatically increase carbon emissions in the future.

REFERENCES

Adam, I., & Pujiati, A. (2025). *Analisis Pengaruh GDP , Urbanisasi , Industrialisasi , dan Foreign Direct Investment Terhadap Emisi CO 2 di ASEAN*. *6*(2), 557–566. https://doi.org/10.47065/jbe.v6i2.7502

Ahmad, A., Wahyudi, H., & Lestari, W. R. (2024). *The Effect of GDP Per Capita , Population , and Income Inequality on CO 2 Emissions in Indonesia*. *14*(1), 365–370.

Ang, J. B. (2007). CO2 emissions, energy consumption, and output in France. *Energy Policy*, *35*(10), 4772–4778. https://doi.org/https://doi.org/10.1016/j.enpol.2007.03.032

Balogh, J. M. (2022). The impacts of agricultural development and trade on CO2 emissions? Evidence from the Non-European Union countries. *Environmental Science & Policy*, *137*, 99–108. https://doi.org/https://doi.org/10.1016/j.envsci.2022.08.012

Begum, R. A., Sohag, K., Abdullah, S. M. S., & Jaafar, M. (2015). CO2 emissions, energy consumption, economic and population growth in Malaysia. *Renewable and Sustainable Energy Reviews*, *41*, 594–601. https://doi.org/https://doi.org/10.1016/j.rser.2014.07.205

Bennedsen, M., Hillebrand, E., & Koopman, S. J. (2024). A regression-based approach to the CO2 airborne fraction. *Nature Communications*, *15*(1), 8507. https://doi.org/10.1038/s41467-024-52728-1

BloombergNEF. (2023). *Vietnam : A Economic Analysis of Power*.

Dengler, J., & Reid, J. (2023). *Emissions and CO 2 Concentration — An Evidence Based Approach*. 1–20.

Espoir, D. K., Sunge, R., & Bannor, F. (2023). Exploring the dynamic effect of economic growth on carbon dioxide emissions in Africa : evidence from panel PMG estimator. *Environmental Science and Pollution Research*, *30*(52), 112959–112976. https://doi.org/10.1007/s11356-023-30108-4

Feriansyah, F., & Larre, A. A. (2022). Economics and Finance in Indonesia Economic Growth and CO2 Emission in ASEAN : Panel-ARDL Approach Economic Growth and CO 2 Emission in ASEAN : Panel-ARDL Approach. *Economics and Finance in Indonesia*, *68*(2). https://doi.org/10.47291/efi.2022.04

Forster, P. M., Smith, C. J., Walsh, T., Lamb, W. F., Lamboll, R., Hauser, M., Ribes, A., Rosen, D., Gillett, N., & Palmer, M. D. (2023). *Indicators of Global Climate Change 2022 : annual update of large-scale indicators of the state of the climate system and human influence*. 2295–2327.

Friedlingstein, P., O'Sullivan, M., Jones, M. W., Andrew, R. M., Bakker, D. C. E., Hauck, J., Landschützer, P., Le

Quéré, C., Li, H., Luijkx, I. T., Peters, G. P., Peters, W., Pongratz, J., Schwingshackl, C., Sitch, S., Canadell, J. G., Ciais, P., Aas, K., Alin, S. R., … Zeng, J. (2025). Global Carbon Budget 2025. *Earth System Science Data Discussions*, *2025*, 1–139. https://doi.org/10.5194/essd-2025-659

Grossman, G. M., & Krueger, A. B. (1995). Economic Growth and the Environment. *The Quarterly Journal of Economics*, *110*(2), 353–377. https://doi.org/10.2307/2118443

Idroes, G. M., Hardi, I., Rahman, H., & Afjal, M. (2024). The dynamic impact of non - renewable and renewable energy on carbon dioxide emissions and ecological footprint in Indonesia. *Carbon Research*. https://doi.org/10.1007/s44246-024-00117-0

IEA. (2022). *An Energy Sector Roadmap to Net Zero Emissions in Indonesia*. https://www.iea.org/reports/an-energy-sector-roadmap-to-net-zero-emissions-in-indonesia

IEA. (2024). *Southeast Asia Energy Outlook 2024*.

IEA. (2025). *Enhancing Indonesia's Power System Pathways to meet the renewables*.

IRENA. (2023). *Geothermal energy.* International Renewable Energy Agency. https://www.irena.org/Energy-Transition/Technology/Geothermal-energy

Justice, G., Nyantakyi, G., & Isaac, S. H. (2024). The effect of renewable energy on carbon emissions through globalization. *Heliyon*, *10*(5), e26894. https://doi.org/https://doi.org/10.1016/j.heliyon.2024.e26894

Karimi Alavijeh, N., Salehnia, N., Salehnia, N., & Koengkan, M. (2023). The effects of agricultural development on CO2 emissions: empirical evidence from the most populous developing countries. *Environment, Development and Sustainability*, *25*(10), 12011–12031. https://doi.org/10.1007/s10668-022-02567-1

Koons, E. (2024). *Geothermal Energy in the Philippines: A Sustainablity Powerhouse.* Energy Tracker Asia. https://energytracker.asia/geothermal-energy-in-the-philippines/

Lean, H. H., & Smyth, R. (2010). CO2 emissions, electricity consumption and output in ASEAN. *Applied Energy*, *87*(6), 1858–1864. https://econpapers.repec.org/RePEc:eee:appene:v:87:y:2010:i:6:p:1858-1864

Lee, H., & Romero, J. (2023). *Climate Change 2023 Synthesis Report IPCC*. https://doi.org/doi.org/10.59327/IPCC/AR6-9789291691647

Luo, B., Rauf, A., Kusi, F. O., Sundas, R., & Mehmood, R. (2024). Exploring the impacts of agricultural emissions from natural gas on ecological footprint. *Ecological Processes*. https://doi.org/10.1186/s13717-024-00558-w

Majekodunmi, T. B., Shaari, M. S., Abidin, N. Z., & Ridzuan, A. R. (2023). Green technology, exports, and CO2 emissions in Malaysia. *Heliyon*, *9*(8), e18625. https://doi.org/https://doi.org/10.1016/j.heliyon.2023.e18625

Mirziyoyeva, Z., & Salahodjaev, R. (2022). Renewable energy and CO2 emissions intensity in the top carbon intense countries. *Renewable Energy*, *192*, 507–512. https://doi.org/https://doi.org/10.1016/j.renene.2022.04.137

Myszczyszyn, J., & Supro´n, B. (2021). *Relationship among Economic Growth (GDP), Energy Consumption and Carbon Dioxide Emission : Evidence from V4 Countries*. https://doi.org/https://doi.org/10.3390/en14227734

Noor, M. A., & Saputra, P. M. A. (2020). Emisi Karbon dan Produk Domestik Bruto : Investigasi Hipotesis Environmental Kuznets Curve (EKC) pada Negara Berpendapatan Menengah di Kawasan ASEAN Carbon Emission and Gross Domestic Product : A Hypothetical Investigation. *JURNAL WILAYAH DAN LINGKUNGAN*, *8*, 230–246. https://doi.org/10.14710/jwl.8.3.230-246.

Osobajo, O. A., Otitoju, A., Otitoju, M. A., & Oke, A. (2020). *The Impact of Energy Consumption and Economic Growth on Carbon Dioxide Emissions*. 1–16.

Our World in data. (2024). *Annual CO_2 emissions*. Our World in Data. https://ourworldindata.org/grapher/annual-co2-emissions-per-country?time=1965..latest&country=~OWID_WRL

Pal, A., Ali, Z., Khan, S. T., Tiwari, C. K., & Bhat, M. A. (2025). *Unveiling the drivers of climate change : the impact of economic indicators , renewable energy consumption and human development through a panel ardl approach*.

Pesaran, M. H., Shin, Y., & Smith, R. J. (2001). BOUNDS TESTING APPROACHES TO THE ANALYSIS. *JOURNAL OF APPLIED ECONOMETRICS*, *326*(February 1999), 289–326. https://doi.org/10.1002/jae.616

Raihan, A. (2023). The dynamic nexus between economic growth, renewable energy use, urbanization, industrialization, tourism, agricultural productivity, forest area, and carbon dioxide emissions in the Philippines. *Energy Nexus*, *9*, 100180. https://doi.org/https://doi.org/10.1016/j.nexus.2023.100180

Rajbhandari, S., Winyuchakrit, P., & Bahadur, B. (2024). Thailand ' s net - zero emissions by 2050 : analysis of economy - wide impacts. *Sustainability Science*, *19*(1), 189–202. https://doi.org/10.1007/s11625-023-01319-y

Rum, I. A., Tukker, A., Hoekstra, R., Koning, A. De, & Yusuf, A. A. (2024). *Exploring carbon footprints and carbon intensities of Indonesian provinces in a domestic and global context*. *October*, 1–15. https://doi.org/10.3389/fenvs.2024.1325089

Sadorsky, P. (2014). The effect of urbanization on CO2 emissions in emerging economies. *Energy Economics*, *41*, 147–153. https://doi.org/https://doi.org/10.1016/j.eneco.2013.11.007

Shahbaz, M., Muhammad, Q., Hye, A., Kumar, A., & Carlos, N. (2013). Economic growth , energy consumption , fi nancial development , international trade and CO 2 emissions in Indonesia. *Renewable and Sustainable Energy Reviews*, *25*, 109–121. https://doi.org/10.1016/j.rser.2013.04.009

Tachev, V. (2024). *Renewable Energy Investments in Vietnam in 2024 – Asia's Next Clean Energy Powerhouse*. Energy Tracker Asia. https://energytracker.asia/renewable-energy-investments-in-vietnam-asias-next-clean-energy-powerhouse/

Tagwi, A. (2022). *The Impacts of Climate Change , Carbon Dioxide Emissions (CO 2) and Renewable Energy Consumption on Agricultural Economic Growth in South Africa : ARDL Approach*. https://doi.org/doi.org/10.3390/su142416468

UNTRAD. (2022). *Review of Maritime Transport*.

Vo, D. H., Vo, A. T., & Ho, C. M. (2024). Urbanization and renewable energy consumption in the emerging ASEAN markets: A comparison between short and long-run effects. *Heliyon*, *10*(9), e30243. https://doi.org/https://doi.org/10.1016/j.heliyon.2024.e30243

Yakymchuk, A., & Maxand, S. (2025). *Economic Analysis of Global CO 2 Emissions and Energy Consumption Based on the World Kaya Identity*. 1–23.

Zhang, X., Shi, X., Khan, Y., Khan, M., Naz, S., Hassan, T., Wu, C., & Rahman, T. (2023). *The Impact of Energy Intensity , Energy Productivity and Natural Resource Rents on Carbon Emissions in Morocco*.

Zheng, S., Pu, Y., Lu, H., Jian, J., Wang, D., & Ma, X. (2023). Global climate policy effectiveness : A panel data analysis. *Journal of Cleaner Production*, *412*(September 2022), 137321. https://doi.org/10.1016/j.jclepro.2023.137321