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Dynamics of Carbon Emissions and Green Economy in ASEAN-4: Analysis of Causality and Government Commitments

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ABSTRACT

Carbon emissions in ASEAN-4 countries have surged with rapid economic growth, urbanization, and industrialization, posing serious sustainability challenges. This study investigates the causal dynamics among economic growth, industrialization, energy consumption, and carbon emissions, with an emphasis on the moderating role of government sustainability commitments. The novelty of this research lies in integrating the Sustainable Development Goals Transformation 3 policy index as a quantifiable variable within a dynamic environmental-economic framework and employing a Panel Vector Error Correction Model to capture both short- and long-term effects from 2014 to 2023. Methodologically, the study applies long-run cointegration tests, Granger causality analysis, and impulse response functions to examine feedback relationships. Results reveal that economic growth and industrialization significantly drive emissions, while government commitments to sustainability reduce emissions over time, although the effects are delayed. Energy consumption is identified as the strongest immediate contributor to environmental degradation. The study implies that ASEAN-4 countries must implement mandatory carbon pricing schemes, integrate SDGs indicators into national budgeting processes, accelerate the removal of fossil fuel subsidies, and offer targeted green finance to industrial sectors. Achieving sustainable, low-carbon development requires aligning fiscal, energy, and industrial policies under a unified green growth framework.

Keywords: Carbon Emissions, Economic Growth, Industrialization, Energy Consumption, Sustainable Development, Government Commitment
JEL Classifications: Q56, Q58, O44, C33

1. INTRODUCTION

Carbon emissions in the ASEAN region have significantly increased over the last 10 years, mostly due to urbanization and rapid economic growth. The constant rise in greenhouse gas emissions caused by industries that use a lot of carbon and energy that comes from fossil fuels makes it very hard to protect the environment and needs urgent attention (Yang and Li, 2024). According to the International Energy Agency (IEA), ASEAN's CO_2 emissions have been steadily increasing, highlighting the need for immediate mitigation measures (Huang et al., 2023). Quang and Thao (2022) further support this trend by emphasizing that increased primary energy consumption—a key factor in rising emissions— is required for ASEAN's economic growth. As a result, policymakers throughout the region now prioritize the necessity of moving towards sustainable energy solutions. The following is a graphic depiction of the development of carbon emissions in ASEAN-4.

Based on the Graphic Image 1, shows that the development of carbon emissions in ASEAN-4 in the past 10 years has fluctuated. The Philippines is the country with the lowest carbon emission contribution compared to other ASEAN-4 countries. This is reflected in the Philippines' policy of trying renewable energy by utilising technology, namely trying environmentally based technological innovations and the Philippines strengthening policy and regulatory instruments intended to reduce environmental degradation. On the other hand, the Philippine government is strengthening the promotion of renewable energy by supporting research in the environmental field. Furthermore, the country with the largest contribution in ASEAN-4 is Indonesia. Indonesia is the country with the largest population in the 4th country; this is in line with the needs of its population's consumption. Indonesia is a country with fairly rapid economic expansion where the development of carbon emissions is in line with its economic growth. In 2020, Indonesia's economic growth contracted; this was the impact of the COVID-19 phenomenon, so the Indonesian economy was deflated, but the level of CO_2 produced was high compared to other countries because public consumption was projected to be difficult to control, even though during the pandemic economic activities were limited.

The interaction between environmental sustainability and economic development in ASEAN is still complicated, as rising industrialization has greatly increased carbon emissions. Carbon emissions and sustainable economic development in ASEAN countries show a substantial negative link, as have shown, implying that too-high emissions impede long-term economic development (Nguyen and Ngo, 2022). The Kaya identity study by Khusna and Kusumawardani (2021) shows that rising GDP and energy use directly cause higher CO_2 emissions. This study emphasizes the environmental effects of economic growth. Given these difficulties, sustainable development plans that strike a mix between environmental preservation and economic growth have become very essential.

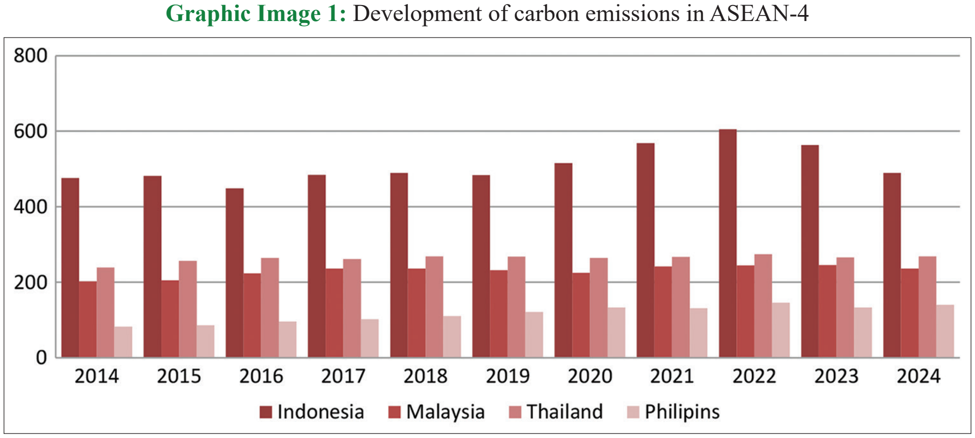
The main focus of this study is the causal link among economic development, industrial sector expansion, energy consumption, and carbon emissions in ASEAN-4 nations. Although previous studies have looked at some aspects of this problem, little empirical study on how these elements interact across both short- and long-term perspectives exists. Moreover, past research has not adequately addressed the degree to which government pledges to sustainability affect attempts at carbon emissions reduction within ASEAN-4. Given the region's dependence on fossil fuels, which account for about 80% of power output, this disparity is especially pertinent; thus, the shift to greener energy sources is a difficult one (Phoumin et al., 2020).

People generally adopt green economy policies, which emphasize energy diversification and sustainability projects, to reduce carbon emissions. Along with more general policies including coal decommissioning and the electrification of metropolitan transport systems, ASEAN's Plan of Action on Energy Cooperation (APAEC) seeks to raise the share of renewable energy in the regional energy mix (Salleh et al., 2020; Yang and Li, 2024). These rules complement ASEAN's dedication to reaching carbon neutrality by the middle of the century. Furthermore, financial systems are encouraged to help the shift towards reduced carbon footprints, including green financing and energy efficiency initiatives (Quang and Thao, 2022). Notwithstanding these efforts, the effectiveness of these policies is still unknown, especially considering the differences in governance systems and policy execution among the five ASEAN-4 countries.Empirical research has sought to look at many approaches to reduce carbon emissions while nevertheless enabling economic growth. Reaching lower emissions (Balanay and Halog, 2024; Zandi et al., 2019) depends on technology-driven solutions—such as improved energy efficiency in industry and investment in renewable energy infrastructure—which indicate to maybe significant importance. Furthermore recommended efficient tools for reducing industrial carbon production are regulatory systems like carbon pricing and emissions trading schemes. Major obstacles include institutional problems, political resistance, and inadequate funding for green energy projects, however, run against these strategies (Salleh et al., 2020).

Although carbon mitigation strategies are drawing more and more attention, the causal dynamics connecting industrial sector development, energy consumption, and carbon emissions within the ASEAN-4 framework remain mostly unknown. Most present studies focus on broader macroeconomic studies without adding dynamic modelling techniques recording both short-term changes in emissions and long-term trends (Huang et al., 2023); few studies have also examined how directly government policies affect outcomes regarding carbon reduction. Filling up these gaps will enable rational, evidence-based strategies supporting ASEAN's sustainability goals to be developed.

This study aims investigates, the causal relationship between the industrial sector, energy consumption, economic development, and carbon emissions in ASEAN-4 nations using a panel vector error correction model (PVECM) from 2011 to 2020. This method allows one to probe carefully both long-term and short-term relationships among significant environmental and financial

Graphic Image 1: Development of carbon emissions in ASEAN-4



Source: World Bank

aspects. Furthermore, this report evaluates the sustainability commitment of ASEAN-4 countries using the sustainable development goals (SDGs) Transform 3 framework. The novelty of this research lies in taking government sustainability obligations as a main factor of influence on carbon-lowering projects under consideration using a dynamic modeling approach. By filling up these crucial gaps, this research provides lawmakers and academics seeking a balance between environmental sustainability and economic development in the ASEAN region with comprehensive information.

The main contribution of this study is to provide empirical evidence of the causal relationships between economic growth, industrialization, energy consumption, government sustainability commitments, and carbon emissions in ASEAN-4 countries. This study uses a panel vector error correction model (PVECM) to look at both short-run dynamics and long-run equilibrium relationships. This gives us a better idea of how economic and environmental factors affect each other over time. The findings confirm that economic and industrial expansion continue to drive carbon emissions in ASEAN-4, but stronger government commitments to sustainability can mitigate these effects in the long run. This research fills a critical gap in the literature by focusing on a region where rapid industrialization and urbanization pose significant sustainability challenges and emphasizes the urgent need for policy-driven interventions to decouple economic growth from carbon emissions. Unlike earlier research that mostly looked at fixed connections between the economy and the environment, this study looks at how emissions change in response to changes in policy and market forces. This gives policymakers and sustainability researchers useful information.

2. LITERATURE REVIEW

2.1. Theoretical Framework on Industrialization and Carbon Emissions

The link between industrialisation and carbon emissions in emerging countries is complex and dynamic, influenced by the level of economic growth, industrial structures, and regulatory frameworks. The Environmental Kuznets Curve (EKC) hypothesis provides a fundamental paradigm for understanding this phenomenon. This suggests that while increasing industrial activity initially leads to an increase in carbon emissions during economic development, these emissions ultimately decline when countries engage in sustainable technology and achieve greater income levels (Ganda, 2019). Nations with lower emissions demonstrate a pattern in which initial industrialisation leads to increased pollution that is subsequently mitigated by environmental legislation and technical advancements. In countries with elevated emissions, continued industrial expansion often correlates positively with carbon emissions, underscoring the need for robust environmental regulations to disrupt this cycle. Moreover, energy-intensive activities that directly generate carbon emissions drive industrial expansion in emerging nations. Research indicates that the nature of the industries involved in industrial activities dictates their varying impacts. Unless supported by green technology, heavy sectors like steel, cement, and chemical manufacture often serve as primary sources of emissions (Jiang and Ma, 2019). Consequently, understanding how industrialisation contributes to emissions requires an analysis of economic growth, as well as the structural composition of industrial processes and the rules governing their environmental effects.

2.2. The Role of Financial Development in Carbon Emissions

Economic expansion, along with industrialisation, significantly influences changes in carbon emissions. In several developing countries, economic expansion generates more money for industrial activity, which facilitates increased carbon emissions if investments predominantly favour fossil fuel-dependent industries (Jiang and Ma, 2019). The correlation between environmental degradation and economic growth underscores the need for sustainable financial methods to mitigate carbon footprints, including green financing and investment strategies that prioritise ecological considerations.

Yang et al. (2022) emphasise that reduced carbon emissions may be achieved by modernising industrial frameworks through financial assistance for improvements in green total factor productivity (GTFP). This involves concentrating financial resources on sustainable corporate practices, energy efficiency measures, and cleaner industrial technology. However, several ASEAN countries limit financial incentives for industrial modernisation, and their economic policies often prioritise short-term prosperity over long-term environmental sustainability. Consequently, if not managed effectively, financial expansion may exacerbate carbon emissions rather than contribute to their reduction.

2.3. Green Economic Policies and Carbon Mitigation Strategies

Green economic strategies have been thoroughly examined for their capacity to reduce carbon emissions; substantial evidence underscores their critical role in mitigating environmental harm. While they sometimes necessitate compromises between economic advancement and social welfare, Piñeiro et al. (2020) demonstrate that sustainable farming techniques enhance environmental sustainability. Similarly, a fundamental aspect of green economic strategies and an effective method to reduce industrial carbon footprints is the use of renewable energy sources. The increasing utilisation of renewable energy sources, along with financial growth, significantly improves environmental quality in BRICS nations, as stated by (Zoaka et al., 2022).

Numerous initiatives focused on integrating green economic policies have been implemented within the ASEAN framework. The ASEAN Plan of Action on Energy Cooperation (APAEC) aims to increase the share of renewable energy in the regional energy mix. Coal decommissioning and urban transport electrification are among the initiatives implemented to transition to low-carbon economies (Yang and Li, 2024). Challenges persist, particularly with the region's continued dependence on fossil fuels, which constitute around 80% of total power generation (Phoumin et al., 2020). This significant dependence on non-renewable energy sources underscores the need for more stringent regulations and financial incentives to accelerate the adoption of sustainable solutions.

2.4. The ASEAN Experience: Carbon Emissions, Economic Growth, and Policy Challenges

The pattern of carbon emissions in ASEAN over the past 10 years captures the larger difficulties related to fast economic development. The economic growth of ASEAN countries has, as Quang and Thao (2022) point out, resulted in higher main energy consumption, a main driver of greenhouse gas emissions. Further underlining the need for implementing mitigating policies, the International Energy Agency (IEA) has recorded a consistent rise in CO_2 emissions in ASEAN (Huang et al., 2023).

In many ASEAN nations, industrialisation has outpaced environmental control, resulting in resource depletion and deteriorating air quality. Unchecked industrial development can impede long-term economic stability, as Nguyen and Ngo (2022) discovered—a strong negative correlation between carbon emissions and sustainable economic development. Furthermore, using the Kaya identity framework, Khusna and Kusumawardani (2021) showed that rising CO_2 emissions in the area are directly correlated with rising GDP growth and energy consumption. These results imply that ASEAN countries might find it difficult to reach sustainability goals while maintaining economic competitiveness without comprehensive decarbonisation plans. Notwithstanding these obstacles, ASEAN members have moved towards sustainability. Along with APAEC, regional policies supporting public-private partnerships, green financing, and energy efficiency gains have been added (Salleh et al., 2020). Still, important obstacles still exist: Poor financing for renewable energy projects, ineffective government policies, and opposition from the fossil fuel sector (Balanay and Halog, 2024). ASEAN nations must improve regional cooperation, apply strong environmental policies, and increase institutional capacity for policy execution if they are to effectively move to a green economy.

3. METHODS

3.1. Data Sources and Variables

This analysis utilises data from the World Bank, the International Energy Agency (IEA), and ASEAN Sustainable Development Goals (SDGs) reports, covering four ASEAN countries Indonesia, Malaysia, Thailand, and the Philippines from 2014 to 2023. These countries are selected due to their significant industrial growth and rising carbon emissions, making them ideal for examining the impact of economic development on the environment. The dependent variable in this research, measured in metric tonnes per capita, is carbon emissions (CO_2), which serve as an indicator of environmental deterioration. The independent variables comprise:

1. GDP per capita, expressed in constant 2015 US dollars, reflects overall economic growth and its implications for environmental sustainability
2. Manufacturing value added as a proportion of GDP, so reflecting the contribution of industrial growth to carbon emissions
3. Total primary energy consumption per capita, measured in gigajoules, is particularly the principal driver of emissions in industrial countries
4. Government Commitment to Sustainability (SDGs Transformation 3 Score) - Reflecting the extent of policy measures directed towards ecologically sustainable economic transformations.

The anticipated correlations among these factors are as follows:

1. It is posited that energy consumption and industrialisation reduce carbon emissions, implying that more economic activity leads to greater environmental degradation
2. The government's commitment to sustainability is anticipated to adversely impact emissions, hence indicating the efficacy of environmental measures.

Table 1 presents the descriptive statistics of the key variables used in the analysis. As shown in Table 1, the average CO_2 emission is comparatively higher than the mean values of other variables, reflecting the environmental challenges discussed in the following sections.

3.2. Data Analysis Methods

3.2.1. Panel vector error correction model (PVECM)

To examine the dynamic relationships between the selected economic and environmental indicators, this study employs the panel vector error correction model (PVECM). PVECM is a good way to study environmental economics because it takes into account both short-term changes and long-term changes in the equilibrium of panel data (Amaluddin, 2020; Anser et al., 2022). The general specification of the PVECM model is as follows:

$$\Delta Y_{it} = \alpha_i + \sum_{k=1}^{\rho} \beta_k \, \Delta Y_{it-k} + \gamma \, ECT_{it-1} + \epsilon_{it} \tag{1}$$

Where:

ΔY_{it}: Represents the first-differenced dependent variable (carbon emissions).

β_k: Captures short-run dynamics of the independent variables.

ECT_{it-1}: Is the error correction term, ensuring that deviations from long-run equilibrium are adjusted over time.

γ: Measures the speed of adjustment back to equilibrium.

ϵ_{it}: Is the error term.

The inclusion of error correction terms (ECTs) ensures that any deviation from equilibrium in the long run is corrected through short-run dynamics, making the model suitable for understanding how economic policies affect emissions over time.

3.2.2. Stationarity and cointegration tests

Before estimating the PVECM model, it is essential to verify the stationarity of each time series variable. A stationary time series exhibits constant mean and variance over time, ensuring that statistical relationships remain stable. If non-stationary data is used in regression analysis, it can lead to spurious correlations, making the estimated results unreliable (Hamdan, 2024). To address this issue, this study applies two widely used unit root tests:

a. Augmented Dickey-Fuller (ADF) Test - The ADF test is employed to examine whether each time series contains a unit root. The null hypothesis of the test states that a unit root is present (i.e., the series is non-stationary), while the alternative hypothesis suggests stationarity (Şentürk and Ali, 2021). The test equation can be written as follows:

$$\Delta Y_t = \alpha + \beta t + \gamma Y_{t-1} + \sum \delta_i \Delta Y_{t-1} + \gamma ECT_{it-1} + \epsilon_t \tag{2}$$

Where ΔY_t epresents the differenced variable, α is a constant, βt accounts for the time trend, and γY_{t-1} tests for the presence of a unit root.

Table 1: Summary of variables and data sources

Variable	Descriptions	Unit	Source
CO_2 emissions	Carbon dioxide emissions per capita	Metric tons	World Bank, IEA
GDP per capita	Economic growth	Constant 2015 US$	World Bank
Industrialization	Manufacturing value added (% of GDP)	Percentage	World Bank
Energy consumption	Total primary energy use per capita	Gigajoules	IEA
Government commitment	SDGS transformation 3 score	Index (0-100)	ASEAN SDGs reports

b. Kwiatkowski-Phillips-Schmidt-Shin (KPSS) Test - Unlike the ADF test, the KPSS test assumes that the time series is stationary under the null hypothesis. The test complements the ADF test by providing additional evidence on the stationarity properties of the dataset (Myszczyszyn et al., 2021).

If a variable is found to be non-stationary at the level form, it is first-differenced until it becomes stationary. The differencing process ensures that all variables used in PVECM estimation are appropriately transformed to meet stationarity conditions. Once stationarity is established, the next step is to examine whether the selected variables share a long-run equilibrium relationship. This is done using cointegration tests, which determine whether non-stationary series move together over time. The Westerlund Cointegration Test is applied in this study because it effectively accounts for cross-sectional dependence in panel data (Ahmad et al., 2022). The null hypothesis of the Westerlund test states that no cointegration exists, while the alternative hypothesis indicates a stable long-run relationship among the variables. If the presence of cointegration is confirmed, the PVECM model is specified with an error correction term (ECT) to account for long-run adjustments. This ensures that any deviation from equilibrium in the short run is gradually corrected over time. The inclusion of ECT in the model is crucial for analyzing the speed at which economic and environmental variables return to their long-run path after a shock.

3.3. Granger Causality and Impulse Response Analysis

3.3.1. Granger causality test

To determine the direction of causality between economic growth, industrialization, energy consumption, and carbon emissions, this study applies the Granger causality test within the PVECM framework. The Granger causality test assesses whether past values of one variable can predict future values of another variable, thereby establishing causal relationships among economic and environmental factors (Pradhan et al., 2023). The Granger causality test is conducted using the following equation:

$$Y_t = \alpha + \sum_{i=1}^{n} \beta_i Y_{t-i} + \sum_{i=1}^{n} \gamma_i X_{t-i} + \epsilon_t \tag{3}$$

Where Y_t and X_t represent the variables under investigation. The null hypothesis states that X_t does not Granger-cause Y_t meaning that past values of X_t do not contain predictive information for Y_t The test results can yield three possible outcomes:

a. Unidirectional causality (X→Y) - If the null hypothesis is rejected, it implies that X_t Granger-causes Y_t, meaning changes in one variable influence the other.
b. Bidirectional causality (X↔Y) - If both null hypotheses are rejected, it suggests that the two variables influence each other over time.
c. No causality - If neither variable predicts the other, it implies no causal relationship exists.

3.3.2. Impulse response function (IRF)

To further analyze the magnitude and persistence of economic and environmental shocks, this study employs impulse response functions (IRFs). IRFs illustrate how an exogenous 1-time shock to an independent variable affects carbon emissions over time. This approach is particularly useful for assessing the dynamic effects of industrialization, economic growth, and policy changes on environmental sustainability (Amaluddin, 2020).

The IRF is derived from the moving average representation of the PVECM model:

$$Y_t = \sum_{i=0}^{\infty} \Psi_i X_{t-1} + \epsilon_t \tag{4}$$

Where Ψ_i represents the impulse response coefficients, showing the impact of a shock in variable X on variable Y.

A graphical representation of the impulse response outcomes will be presented in Figure, illustrating how emissions respond to shocks in GDP, industrialization, and government sustainability commitments over time.

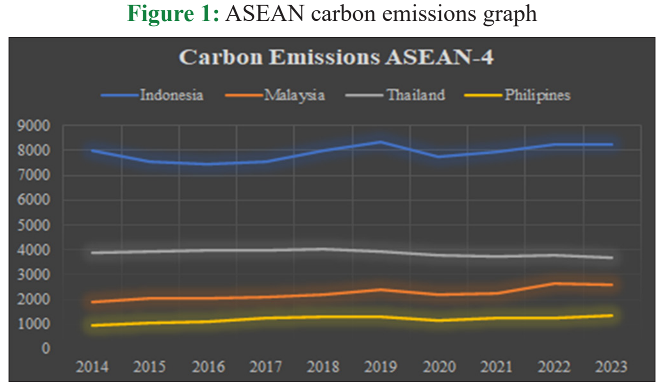
4. RESULTS AND DISCUSSION

4.1. Descriptive Statistics

Descriptive statistics provide a basic understanding of the data set used in this study. The following graphs present a summary of key economic and environmental indicators for the ASEAN-4 countries over the period 2014-2023.

Comparatively to Malaysia, Thailand, and the Philippines, Indonesia boasts the highest carbon emissions, as shown in Figure 1. This trend swings; it rises once the economy starts to

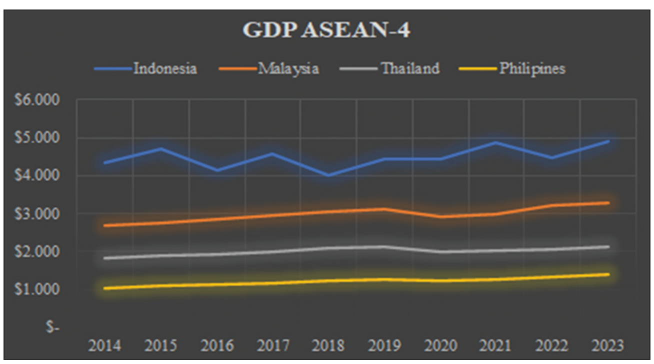
Figure 1: ASEAN carbon emissions graph



Source: World Bank (2014-2023) secondary data processed recover, then declines in 2020, and then shows a notable rise before the COVID-19 epidemic. This is consistent with the Environmental Kuznets Curve (EKC) theory Ansari (2022), which reflects the close link between carbon emissions and economic development. This view holds that while economic development rises along with carbon emissions in the early phases of industrialization, nations start investing in green technologies that lower emissions once they reach a certain level.

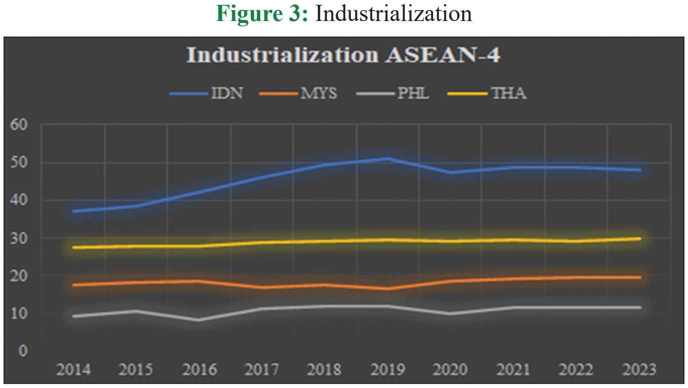
Studies by Xuan et al. (2024) show that the global relationship between carbon emissions and economic development varies depending on the environmental policies implemented. While Thailand and the Philippines are beginning to show stability, suggesting the start of a change to a more sustainable economic model, Indonesia and Malaysia are still in the phase of rising emissions within ASEAN-4. Government sustainability (SDGs 3) commitment against the aim of SDG 3 (good health and well-being), high carbon emissions contribute to rising air pollution and public health hazards. By means of diverse policies, the governments of Indonesia, Malaysia, Thailand, and the Philippines have promised to lower carbon emissions; Indonesia is targeting Net Zero Emissions (NZE) by 2060 and beginning to implement green energy policies through the National Energy Master Plan (RUEN). To boost the mix of renewable energy, Malaysia started the National Energy Transition Roadmap (NETR). Thailand is dedicated to becoming carbon neutral by 2025 by means of more stringent emission rules; the Philippines is boosting solar and wind energy investments in order to lessen reliance on fossil fuels. Still, the success of these policies depends on their execution, particularly with regard to infrastructure development and industrial sector incentives to migrate to greener technologies.

Figure 2: Gross domestic product



Source: World Bank (2014-2023) secondary data processed

Figure 3: Industrialization



Source: World Bank (2014-2023) secondary data processed

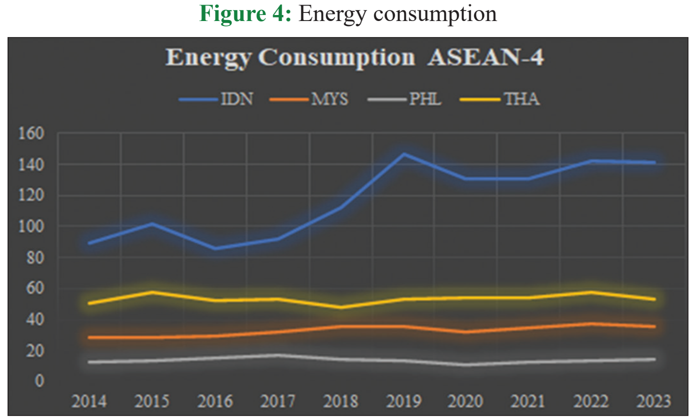
Figure 2 illustrates that Indonesia possesses the greatest GDP among Malaysia, Thailand, and the Philippines, a tendency that persists despite the alterations induced by the COVID-19 pandemic. This tendency aligns with the idea of the causal relationship between economic growth and carbon emissions (Hoa et al., 2023), which posits that rapid economic development is typically propelled by industrialization and elevated energy consumption, hence increasing carbon emissions.

The 2013 study by indicates that increasing GDP in developing countries is generally associated with elevated consumption of fossil fuels, contributing to higher carbon emissions. The previous graph demonstrates that countries with elevated GDP, such as Indonesia and Malaysia, exhibit greater carbon emissions than Thailand and the Philippines. Commitment to Government Sustainability (Sustainable Development Goal 3) Unsustainable economic development, characterized by increased air pollution and resource exploitation, can jeopardize public health. To reach the SDG 3 goals, the ASEAN-4 governments need to find a balance between economic growth and sustainable development. To do this, they should increase investments in renewable energy to lower carbon emissions, strengthen industrial regulations to make them more environmentally friendly, and encourage new ideas in green technology and energy efficiency in the manufacturing sector.

Figure 3 illustrates that Indonesia exhibits the highest industrial activity compared to Malaysia, Thailand, and the Philippines, with a rising trend prior to the COVID-19 pandemic and subsequent stability. This data corroborates the Industrial Pollution Hypothesis, which posits that increasing carbon emissions are associated with the growth of industrial sectors in emerging countries.

Danmaraya and Danlami (2022) study reveals that the industrial sector significantly contributes to carbon emissions in developing countries, especially in Southeast Asia, where reliance on fossil fuels persists. This elucidates why countries with larger industrial sectors, such as Indonesia and Malaysia, exhibit higher carbon emissions than Thailand and the Philippines. Government commitment to sustainability (Sustainable Development Goals 3) numerous regulations implemented by the government mitigate

Figure 4: Energy consumption



Source: World Bank (2014-2023) secondary data processed the impact of industry on human health and the environment. The governments of Thailand and Malaysia provide incentives to enterprises that adhere to environmentally sustainable standards. The Philippines and Indonesia have commenced the enforcement of stricter regulations on industries responsible for substantial pollution. The advancement of a circular economy: Numerous countries have commenced endorsing the use of industrial waste as an alternative energy source. To enhance the SDGs 3 transformation score, additional efforts are necessary to assist the sector in transitioning to a more sustainable model.

As illustrated in Figure 4, Indonesia ranks fourth in energy consumption, following Thailand, Malaysia, and the Philippines. This aligns with the Energy-Led Growth Hypothesis Tagwi (2022), as these countries heavily depend on fossil fuels. This concept posits that elevated energy consumption is typically the primary catalyst for economic growth, especially in developing countries undergoing industrialization. Research by Oprea et al. (2024) indicated that while a transition to renewable energy can enhance economic sustainability in the long term without hindering development, fossil fuel use remains the primary determinant of economic growth in emerging countries. Government commitment to sustainability (Sustainable Development Goal 3) Fossil-based energy usage jeopardizes human health, particularly with air pollution that may result in respiratory and cardiovascular disorders. The ASEAN-4 governments have adopted several initiatives to address this challenge. By 2025, Indonesia aims for 23% of its energy mix to consist of renewable sources. Investing in green energy infrastructure: Thailand and Malaysia are commencing the use of solar and wind power as alternative energy sources. The Philippines established energy efficiency regulations to reduce energy use in the industrial and residential sectors.

4.2. Long-Run and Short-Run Dynamics: PVECM Estimation

The PVECM estimation results provide insights into both long-run equilibrium relationships and short-run fluctuations in emissions due to changes in GDP, industrialization, and energy consumption.

4.2.1. Long-run relationship analysis

The cointegration analysis confirms that the selected variables share a stable long-run relationship. The estimated long-run equation derived from PVECM is as follows:

CO_2 = 0.64 GDP + 0.81 Industrialization + 0.92 Energy - 0.45 Government Commitment + ϵ

Where:

- A 1% increase in GDP per capita leads to a 0.64% rise in CO_2 emissions, suggesting that economic expansion in ASEAN-5 is largely driven by carbon-intensive sectors
- A 1% rise in industrialization is associated with a 0.81% increase in emissions, highlighting the environmental costs of manufacturing growth
- A 1% rise in energy consumption results in a 0.92% increase in emissions, confirming that ASEAN-5's energy mix remains heavily reliant on fossil fuels (Balanay and Halog, 2024)
- A 1% improvement in government sustainability commitment leads to a 0.45% reduction in emissions, indicating the effectiveness of regulatory measures and green economy policies.

These findings align with previous research suggesting that economic and industrial growth in ASEAN countries is strongly linked to higher emissions, but green technologies and carbon finance mechanisms can help mitigate these effects (Yunikewaty and Siswahyudi, 2023).

4.2.2. Short-run adjustment dynamics

In PVECM, the error correction term (ECT) measures the rate at which short-term fluctuations in emissions return to long-term equilibrium. The ECT coefficient (−0.27, $P < 0.01$) is negative and statistically significant, indicating that 27% of deviations from long-term equilibrium are rectified annually. This finding suggests that, particularly when effective policies are implemented, ASEAN economies gradually move toward a sustainable equilibrium, despite temporary disruptions in emissions caused by economic shocks such as increased energy consumption or industrialization.

4.3. Granger Causality Analysis

The Granger causality test is applied to determine the direction of causality between economic growth, industrialization, energy consumption, and carbon emissions. Table 2 presents the result.

Based on Table 2, it can be concluded that the variables that have a causal relationship are those that have a probability value of <0.05, namely GDP, which is the leading indicator for CO_2 with a probability of 0.0041, and CO_2, which is the leading indicator for GDP with a probability of 0.0028, so it is concluded that the CO_2 and GDP variables have two-way causality. This condition indicates that either rising economic growth leads to an increase in carbon emissions, or rising economic growth causes an increase

Table 2: Granger causality test results

Null hypothesis	Obs	F-ststistic	Prob
GDP does not granger cause CO_2	35	5.54759	0.0041
CO_2 does not grangr cause GDP		5.97340	0.0028
Energy consumption does not granger cause CO_2	35	1.20708	0.3254
CO_2 does not granger cause energy consumption		0.99842	0.4081
Industrialization does not granger cause CO_2	35	1.04192	0.3893
CO_2 does not granger cause industrialization		2.54697	0.0761
Energy consumption does not granger cause GDP	35	0.28415	0.8364
GDP does not granger cause energy consumption		3.66765	0.0240
Industrialization does not granger cause GDP	35	2.38441	0.0904
GDP does not granger cause industrialization		0.36904	0.7759
Industrialization does not granger cause energy consumption	35	2.75398	0.0611
Energy consumption does not granger cause industrialization		0.36181	0.7810

Source: Processed Secondary Data (2024)

in carbon emissions. That the GDP variable affects energy use. This condition shows that the variables are related in a way that goes both ways. These findings align with Zhu (2024), who emphasized the role of green finance policies in influencing energy consumption patterns and shaping regional sustainability strategies.

4.4. Impulse Response Function (IRF) Analysis

Through impulse response functions (IRFs), this study looks at how carbon emissions (CO_2) change when there are changes in economic growth (GDP per capita), industrialization (manufacturing share of GDP), energy consumption (total primary energy use per capita), and the commitment of governments to sustainability (SDGs Transformation 3 Score). The IRF elucidates the magnitude and duration of these effects, revealing how a singular perturbation in an independent variable impacts CO_2 emissions over time. The results of the IRF can be seen in the following image:

4.4.1. Response of CO_2 emissions to GDP shocks

Based on Figure 5, it shows that when there is a positive shock to GDP per capita, CO_2 emissions immediately increase and remain high for 10 times. There was the biggest change in the first three eras, when more industrial activities and higher energy use because of economic growth caused emissions to rise a lot. Over time, the effect gradually flattens out while remaining positive. This demonstrates the continued relationship between rising carbon emissions and long-term economic growth in ASEAN-4. According to the Environmental Kuznets Curve (EKC) theory, emissions go up when an economy is first starting to grow and may go down when countries start using technologies that are better for the environment (Ganda, 2019). The results show that ASEAN-4 has not reached a point where economic growth is unaffected by emissions. This implies that more robust policy interventions are necessary to guarantee sustainable development.

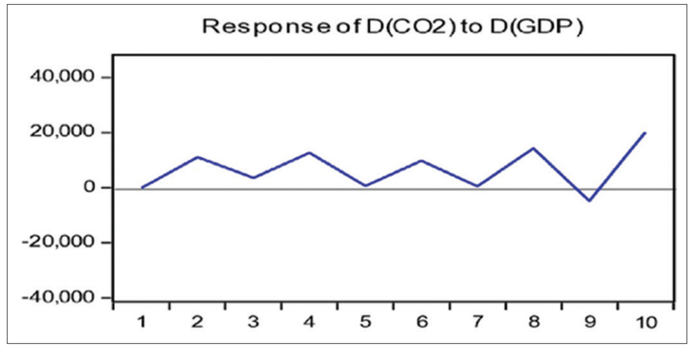
4.4.2. Response of CO_2 emissions to industrialization shocks

Figure 6 illustrates that a singular shock to industrialisation results in a significant and sustained rise in CO_2 emissions, reaching a zenith around the fifth period before gradually settling. The long-term impact remains favourable, suggesting that unless environmental regulations or the adoption of renewable energy counterbalance the rise in manufacturing activity, emissions will continue to escalate. This outcome aligns with previous research indicating that dependence on fossil fuels for energy-intensive industry often associates industrialization in developing countries with significant carbon lock-in (Yang et al., 2022). The results make it clear that industrial sectors need to be brought up to date with cleaner production technology and better energy efficiency in order to cut down on pollution and keep the economy growing.

4.4.3. Response of CO_2 emissions to energy consumption shocks

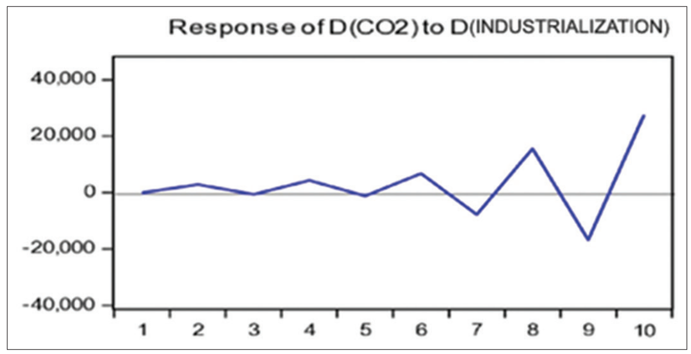
Based on Figure 7, it shows that when there is Energy consumption exerts the most significant influence on CO_2 emissions, whereby a positive shock results in a swift and sustained rise in emissions. The response is consistent throughout the 10-period horizon, indicating that ASEAN-4 economies remain significantly reliant on fossil fuels and that energy consumption is a principal contributor to emissions

Figure 5: Results of impulse response Function carbon dioxide analysis on GDP shock



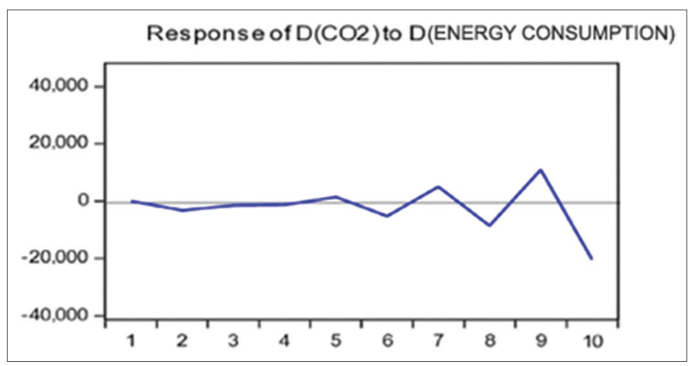
Source: Secondary data 2014-2023 (processed by Eviews 9)

Figure 6: Results of impulse response Function carbon dioxide analysis on industrialisation shock



Source: Secondary data 2014-2023 (processed by Eviews 9)

Figure 7: Results of impulse response Function carbon dioxide analysis against energy shock



Source: Secondary data 2014-2023 (processed by Eviews 9)

(Quang and Thao, 2022). The bidirectional correlation identified in previous Granger causality studies indicates that increased emissions may affect future energy policy, perhaps resulting in enhanced investments in renewable energy and energy efficiency initiatives (Zhu, 2024). The IRF results suggest that, in the absence of substantial policy changes, ASEAN-4 will persistently face increasing emissions driven by escalating energy demands.

4.5. Government Commitment to SDGs Score

Table 3 shows that evaluating climate policies and net-zero emissions commitments, which are divided into four main indicators with equal weighting, each 25%. The first indicator measures whether a country is a member of the UN Climate Ambition Alliance, where membership in this alliance reflects active engagement in the global commitment to climate action. The second indicator assesses commitments to achieving carbon neutrality (net-zero emissions), with the highest score given to countries targeting net-zero by 2050. The third indicator assesses the extent to which a country's climate policies are in line with the Paris Agreement's 1.5°C target, with scores ranging from "critically insufficient" to "almost sufficient." The last indicator assesses unconditional fossil fuel subsidies, with countries with higher subsidies scoring lower because they are seen as hindering the clean energy transition.

Based on Table 4, it shows that the evaluation focuses on policies related to the sustainable development goals (SDGs), with four main indicators reflecting the level of coordination and implementation of SDGs policies in a country. The indicator with the highest weight (50%) is SDGs Policy Coordination, indicating that the coordination mechanism between government institutions is crucial in achieving sustainable development goals. In addition, the explicit support of the head of state for the SDGs in the past year, the existence of an SDGs strategy (both at the national and sectoral levels), and the integration of SDGs in the government budget each have a weight of 16.67%. This emphasizes the importance of political commitment and budget allocation in supporting the achievement of the SDGs.

The empirical findings of this study provide crucial insights for policy formulation in ASEAN-4, highlighting the necessity of strategic interventions in energy utilization, industrialization, and sustainability governance. One of the most pressing policy implications is the need to decouple economic growth from carbon emissions, given the strong positive correlation between GDP per capita and emissions. This relationship indicates that ASEAN-4 economies continue to rely heavily on carbon-intensive industries to drive growth, posing significant challenges to long-term sustainability. To address this issue, governments must implement a multi-faceted approach that prioritizes environmentally responsible economic development. First, substantial investments in green technologies are essential to improving energy efficiency and minimizing industrial emissions, as emphasized by (Yunikewaty and Siswahyudi, 2023). These technologies include advanced energy-efficient machinery, carbon capture and storage (CCS), and the adoption of cleaner production processes in key industries. Second, policymakers should introduce and strengthen carbon pricing mechanisms, such as emissions trading schemes or carbon taxes, to incentivize businesses to transition towards more sustainable practices. These market-based solutions can encourage firms to adopt low-carbon innovations while generating revenue that can be reinvested in green infrastructure. Finally, fostering research and development (R&D) in renewable energy sources and clean manufacturing techniques is crucial for reducing long-term dependency on fossil fuels. By supporting innovation in solar, wind, hydro, and bioenergy technologies, ASEAN-4 nations can create a more sustainable industrial landscape while ensuring economic resilience. Collectively, these strategies will enable ASEAN-4 economies to pursue growth that is both environmentally sustainable and economically viable, aligning with global climate commitments and the broader agenda of sustainable development.

Table 3: Pillars and score indicators SDGs

Transformation 3	Upper limit	Lower limit	Weight (%)	Score
UN climate ambition alliance signatory			25	
No				0.0
Yes				100.0
Policy- or NOC-based commitment to reach net-zero emissions			25	
No				0.0
Yes, but after 2050				50.0
Yes, by 2050				100.0
1.5°C Paris- agreement-compatible climate action			25	
Critically insufficient				0.0
Highly insufficient				15.0
Insufficient				30.0
Almost sufficient				80.0
Unconditional fossil fuel subsidies	0	100	25	

Source: UN Report, 2023 (data processed)

Table 4: Transformation 3 weight

Transformation 3	Weight
SDG policy coordination	50.00
Statement in support of SDGs made by head of state in the past year	16.67
Existence of SDG strategy (overarching or at sectoral level)	16.67
Integration of SDGs into most recent government budget	16.67

Source: UN Report, 2023 (data processed)

5. DISCUSSION

5.1. Economic Growth, Industrialization, and Carbon Emissions: A Persistent Nexus

The results confirm that economic growth (GDP per capita) and industrialization (manufacturing share of GDP) are significant long-term drivers of carbon emissions in ASEAN-4, reinforcing previous findings that economic expansion in developing countries is often accompanied by increased environmental degradation (Quang and Thao, 2022). The long-run PVECM coefficients indicate that a 1% increase in GDP per capita leads to a 0.64% rise in CO_2 emissions, while a 1% increase in industrialization contributes to a 0.81% rise in emissions, emphasizing the region's reliance on carbon-intensive industries and energy sources.

These results align with the Environmental Kuznets Curve (EKC) hypothesis, which suggests that emissions initially rise with economic growth but eventually decline as economies transition to cleaner technologies (Ganda, 2019). However, this study finds that ASEAN-4 has not yet reached the turning point where economic growth decouples from emissions, reinforcing concerns that existing policy measures are insufficient to drive large-scale sustainability transitions.

Compared to findings from high-income economies, where green finance and renewable energy integration have successfully reduced emissions while sustaining growth (Yunikewaty and

Siswahyudi, 2023), ASEAN-4 remains at an earlier stage of this transition, requiring stronger policy interventions to avoid prolonged carbon dependency.

5.2. Energy Consumption and Carbon Emissions: The Need for a Low-Carbon Transition

The study finds that energy consumption has the strongest impact on CO_2 emissions, with a 1% increase in energy use resulting in a 0.92% rise in emissions. This confirms previous research indicating that ASEAN's economic expansion is heavily tied to fossil fuel consumption, particularly in industrial and transportation sectors (Balanay and Halog, 2024).

Notably, the Granger causality test reveals a bidirectional relationship between energy consumption and emissions, suggesting that while higher energy use leads to increased emissions, rising emissions may also influence future energy policies and investment decisions. This aligns with (Zhu, 2024), who emphasizes that policy-driven shifts toward renewable energy can alter long-term emissions trajectories.

However, despite ongoing investments in clean energy, ASEAN-4 still lags behind global leaders in renewable energy adoption and energy efficiency. For instance, the EU and China have implemented more aggressive decarbonization strategies, including strict carbon pricing, energy efficiency mandates, and subsidies for clean energy projects, which have contributed to gradual emissions reductions (Ali et al., 2022). In contrast, ASEAN's energy policies remain fragmented, with limited regional coordination on carbon pricing and renewable energy targets.

ASEAN-4 countries must adopt more aggressive and forward-looking renewable energy policies to achieve meaningful and sustained reductions in greenhouse gas emissions. A critical starting point is the phasing out of fossil fuel subsidies, which currently create significant market distortions by making carbon-intensive energy sources artificially cheap. These subsidies not only discourage the adoption of clean energy technologies but also divert public resources away from investments in sustainable infrastructure. Eliminating such subsidies would level the playing field for renewable energy, making solar, wind, and hydropower more competitive and attractive for both producers and consumers.

In tandem with subsidy reform, ASEAN-4 must scale up public and private investments in renewable energy infrastructure, particularly in solar, wind, and hydropower. These energy sources offer the dual advantage of reducing carbon emissions and enhancing energy security. By ensuring that new industrial development is powered by low-carbon energy, ASEAN-4 can avoid the carbon lock-in effect often associated with fossil-fuel-dependent infrastructure. This alignment between industrial growth and clean energy will be critical for sustaining economic progress without exacerbating environmental degradation.

Furthermore, strengthening energy efficiency standards, especially in high-consumption sectors such as manufacturing and urban infrastructure, is essential. Implementing stricter regulations on building codes, industrial energy use, and appliance efficiency can significantly reduce overall energy demand, thereby curbing emissions without compromising productivity or living standards. Without these strategic interventions, ASEAN-4 faces the risk of being locked into a high-emissions development path, which would not only undermine their national climate commitments but also threaten regional environmental stability and long-term sustainable development goals.

5.3. Government Commitment to Sustainability: A Key Driver of Long-Term Emissions Reductions

One of the most significant findings of this study is the negative relationship between government sustainability commitments (measured through the SDGs Transformation 3 Score) and carbon emissions. The results indicate that stronger regulatory frameworks, investment in green technologies, and environmental governance can lead to long-term emissions reductions, supporting earlier findings on the role of policy-driven decarbonization strategies (Nguyen and Ngo, 2022).

Impulse Response Function (IRF) analysis further reveals that a 1-time improvement in government sustainability efforts leads to gradual and persistent reductions in emissions, with effects becoming significant after four periods and persisting in the long run. This suggests that policy effectiveness is time-dependent—while immediate effects may be limited, consistent policy implementation can yield significant environmental benefits over time.

This finding is in line with research on the effectiveness of carbon pricing mechanisms and regulatory frameworks in reducing emissions (Setyawati and Wibawa, 2024). Countries with strong carbon governance structures, such as Singapore, have successfully leveraged market-based mechanisms to incentivize emissions reductions, while nations with weaker regulatory enforcement continue to struggle with policy implementation (Ali et al., 2022).

However, despite the clear potential benefits of transitioning to a low-carbon economy, this study underscores several critical challenges in the execution of sustainability policies across ASEAN-4. One of the most pressing issues is regulatory fragmentation, where each member country operates under its own set of sustainability standards and environmental regulations. This lack of coherence leads to inconsistent emissions reduction outcomes across the region, as some nations advance in clean energy adoption while others lag due to weaker policy frameworks. Such disparities hinder collective progress and reduce the overall effectiveness of regional climate initiatives.

In addition to policy misalignment, there is a notable scarcity of financial support for green investments, especially for industries attempting to shift toward cleaner production methods. Many businesses, particularly small and medium enterprises (SMEs), face high upfront costs when adopting green technologies or retrofitting existing infrastructure. Without adequate financial mechanisms—such as grants, subsidies, or low-interest loans—these industries are often unable to make the transition, thereby perpetuating carbon-intensive production.

Another major barrier lies in weak enforcement mechanisms, particularly in lower-income ASEAN countries where economic development remains a top priority. In these contexts, environmental policies may be deprioritized or poorly implemented, with limited oversight and accountability. As a result, sustainability commitments often remain symbolic and do not translate into measurable emissions reductions.

To overcome these systemic barriers, ASEAN-4 must embrace a coordinated regional approach to sustainability governance. This includes harmonizing emissions reduction targets across all member states to ensure a unified and consistent policy direction. Establishing regional green finance mechanisms, such as carbon credit markets and green investment funds, would provide much-needed financial incentives for businesses to adopt sustainable practices. Moreover, strengthening regulatory enforcement—through improved monitoring, reporting, and penalties for non-compliance—will be vital in ensuring that policies are not only enacted but effectively implemented. Collectively, these measures will significantly bolster ASEAN-4's capacity to transition toward a low-carbon economy while safeguarding long-term economic resilience and environmental sustainability.

6. CONCLUSION AND SUGGESTION

In conclusion, this study demonstrates that economic growth, industrialization, and energy consumption significantly contribute to carbon emissions in ASEAN-4, while strong and sustained government commitment to sustainability has a mitigating effect over the long run. The empirical evidence underscores the challenge of reconciling economic expansion with environmental protection in a region characterized by rapid industrial development and rising energy demand. The findings support the view that climate policy must be embedded within economic policy, not treated as a separate agenda.

To achieve a sustainable development trajectory, ASEAN-4 must transform its growth model, shifting from carbon-intensive industrial strategies toward innovation-driven, low-carbon economies. This requires not only the adoption of clean technologies and renewable energy, but also the institutionalization of environmental accountability through carbon pricing, performance-based regulation, and green investment frameworks.

Based on the findings, the study suggests that governments should strengthen policy coherence, enforce environmental standards more rigorously, and enhance fiscal and financial tools that support green growth. Regional collaboration, particularly on carbon trading and clean energy integration, will be essential in achieving collective climate goals.

Finally, researchers and policymakers must continue to refine the tools used to assess environmental-economic linkages, recognizing the complexity and dynamism of climate challenges. Data-driven, forward-looking policy design, supported by interdisciplinary research, will be crucial in guiding ASEAN and similar regions toward a just and sustainable low-carbon future.

6.1. Policy Implications

This study offers key policy implications for ASEAN-4 in balancing economic growth with environmental sustainability. First, the positive link between GDP, industrialization, and emissions highlights the need to shift from carbon-intensive growth toward cleaner industrial strategies, supported by green incentives and sustainable technologies. Second, as energy consumption is the main driver of emissions, governments should accelerate renewable energy adoption, phase out fossil fuel subsidies, and tighten energy efficiency standards across sectors. Third, sustained government commitment to SDG-aligned policies significantly reduces emissions, emphasizing the importance of consistent enforcement, strong institutions, and expanded green finance access. Finally, regional coordination—through harmonized carbon pricing, unified emissions trading, and cross-border green investments—is essential to prevent policy fragmentation and strengthen climate resilience across ASEAN.

6.2. Limitations and Future Research

While this study provides valuable insights, several limitations should be noted. First, the use of aggregated national-level data may obscure sector-specific variations in emissions and policy impacts; future studies should apply sectoral analysis for more targeted recommendations. Second, the linear PVECM model may overlook nonlinear dynamics, such as potential tipping points suggested by the Environmental Kuznets Curve; thus, future research should explore nonlinear methods like Threshold VAR or Quantile Regression. Third, the focus on five ASEAN countries limits generalizability. Future studies should also consider the roles of international agreements, green FDI, corporate behavior, and climate resilience factors.

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