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IMPACT OF RENEWABLE ENERGY CONSUMPTION, INDUSTRIALIZATION, AND TRADE OPENNESS ON CARBON EMISSIONS AMID URBANIZATION AND ECONOMIC GROWTH: A STUDY OF 9 ASEAN COUNTRIES

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Abstract

This study investigates the impact of renewable energy consumption, industrialization, urbanization, trade openness, and economic growth on carbon emissions in nine ASEAN countries namely Indonesia, Malaysia, the Philippines, Singapore, Thailand, Vietnam, Laos, Cambodia, and Brunei over the period 1994 to 2023. Using panel data regression methods with Fixed Effect Model (FEM) and Common Effect Model (CEM) based on Chow and Hausman tests, the results show that renewable energy consumption has a statistically significant negative effect on carbon emissions. In contrast, industrialization, trade openness, and economic growth exert positive influences. Urbanization presents varied effects depending on the country's development level and institutional quality. These findings provide empirical evidence supporting the role of renewable energy in emissions reduction, while also highlighting the environmental risks associated with rapid industrial and economic expansion in the absence of sustainable policies. Policymakers are advised to design integrated energy, industrial, and trade policies that align with regional low-carbon development goals and to strengthen cooperation under the ASEAN Plan of Action for Energy Cooperation (APAEC) framework.

Keywords: ***Carbon emissions; Industrialization; Renewable energy; Trade Openness; Urbanization***

INTRODUCTION

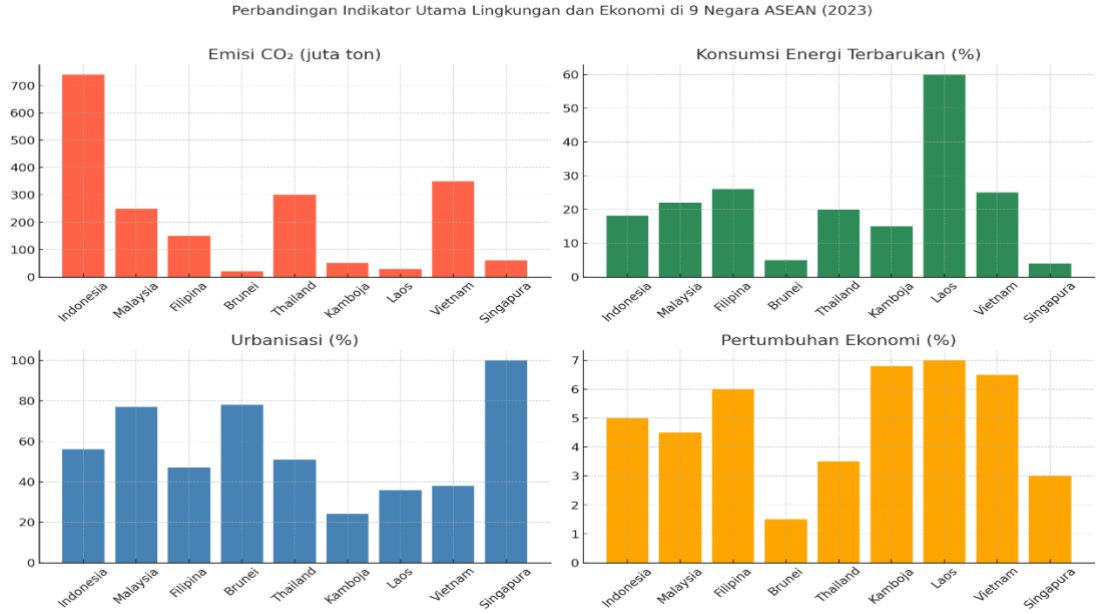
Climate change triggered by increasing carbon emissions has become a serious threat to sustainable development, especially in the Southeast Asian region. ASEAN countries face a dilemma between the demands of economic development and environmental protection. Based on the IEA report (2023), total carbon emissions from nine ASEAN countries, especially Indonesia, Malaysia, the Philippines, Brunei, Thailand, Cambodia, Laos, Vietnam, and Singapore have increased by more than 70% since 2000. This phenomenon requires a deeper understanding of the factors causing emissions, including energy consumption, industrialization, and demographic changes (Lee & Brahmasrene, 2023). Renewable energy is a new hope in the sustainable energy transition in this region. Indonesia, for example, has great potential for solar and hydro energy, but in 2022 only around 13% of its total energy consumption comes from renewable sources (Ministry of Energy and Mineral Resources, 2023). Malaysia and the Philippines show an increasing trend in solar and wind power generation capacity, while Laos and Vietnam are starting to stand out in hydropower development. However, dependence on coal is still dominant in many ASEAN countries (Nguyen & Tran, 2023). Brunei, with high per capita energy consumption, is still highly dependent on oil and gas.

The industrialization process also plays a significant role in increasing carbon emissions. Thailand and Vietnam are the two countries with the fastest industrial expansion, especially in the manufacturing and electronics sectors. On the other hand, Cambodia and Laos are still in the early stages of industrialization, but show a rapid growth trend. A study by Rizal and Amalia (2024) shows that countries with rapid industrial growth but without low-carbon technology tend to experience a spike in emissions, such as in the Mekong Delta region and western Indonesia. Urbanization also exacerbates environmental pressures. Singapore, as a city-state, has the highest urbanization rate (100%) but has succeeded in reducing per capita emissions through energy efficiency and public

transportation policies. This is in contrast to the Philippines and Indonesia, where rapid urbanization is not accompanied by adequate city governance, which has led to a spike in energy consumption and air pollution in big cities such as Manila and Jakarta (Choi & Lim, 2023). In Laos and Cambodia, urbanization has been slower but is beginning to show similar signs.

Economic growth also complicates this dynamic. Countries such as Vietnam and Indonesia have shown economic growth above 5% over the past decade, but this has also been accompanied by increasing carbon emissions. According to Hasan and Lee (2024), economic growth without a green approach tends to drive carbon intensity. In addition, the level of trade openness also contributes to increased economic activity and energy consumption, especially through increased exports and imports and global integration that accelerates industrialization.

Trade openness reflects the extent to which an economy is connected to other countries' economies. According to the World Bank, this indicator is measured by the ratio of total exports and imports of goods and services to Gross Domestic Product (GDP), known as trade (% of GDP). Trade openness plays an important role in determining how much a country interacts in export-import activities with international partners. Not only does it affect exports, trade openness also has a major impact on imports, especially since many investors rely on raw materials or components obtained from abroad. The higher the level of trade openness, the greater the investment opportunities and strengthening of relations between domestic and global markets.



Sources: DataIndonesia.id, GoodStats.id, Gokepri.com, IDXChannel.com

Figure 1. Key indicators (CO_2 emissions, renewable energy, urbanization, and economic growth) in 9 ASEAN countries in 2023

The first graph shows that Indonesia is the largest contributor of carbon emissions in the ASEAN region with total emissions reaching 740 million tons of CO_2 in 2023. This figure far exceeds other countries such as Vietnam (350 million tons) and Thailand (300 million tons), which also have quite dominant fossil-based industrial and power generation sectors. In contrast, countries such as Brunei, Laos, and Singapore have relatively low carbon emissions. Interestingly, even though Singapore is a developed and highly urbanized country, its carbon emissions are only 60 million tons. This shows that the level of economic development is not always in line with the amount of emissions, because energy efficiency factors and the use of clean technology play a major role in reducing the amount of emissions. In the renewable energy consumption indicator, there is a large variation between countries. Laos is in the top position with 60% of energy consumption coming from renewable sources, dominated by hydroelectric power plants.

The Philippines and Malaysia also show quite high figures, 26% and 22% respectively. In contrast, Singapore and Brunei have the lowest figures, at only 4% and 5%. This fact reflects that the availability of natural resources and the direction of energy policy greatly influence the penetration of renewable energy in each country. Although countries such as Singapore have high fiscal and technological capacity, geographical limitations and

different energy priorities are obstacles to the green energy transition. Meanwhile, the highest urbanization rate was achieved by Singapore (100%), followed by Brunei and Malaysia, each above 75%. On the other hand, countries such as Cambodia, Laos, and Vietnam have low urbanization rates, below 40%.

High urbanization generally has an impact on increasing energy consumption and mobility, which has the potential to drive carbon emissions. However, in the case of developed countries such as Singapore, urbanization does not necessarily lead to increased emissions, thanks to the implementation of strict environmental policies and efficient city infrastructure. This shows that urbanization can be managed sustainably if accompanied by the right policies. In terms of economic growth, Laos recorded the highest figure of 7.0%, followed by Cambodia and Vietnam, each above 6%. These countries show rapid economic dynamics as developing countries. In contrast, developed countries such as Singapore and Brunei recorded more moderate growth, ranging from 1.5–3.0%. This difference indicates that developing countries face a dual challenge: maintaining economic growth while reducing their environmental impact. Without a sustainable development strategy, rapid economic growth can lead to a spike in carbon emissions, especially if they still rely on fossil fuels.

Overall, this comparison chart shows the disparity between developed and developing countries in ASEAN in terms of energy consumption, carbon emissions, and economic structure. Developed countries such as Singapore tend to have more controlled emissions despite their urbanization and high income, thanks to efficient technology and policies. In contrast, developing countries such as Indonesia and Vietnam are still struggling to balance industrialization and emission control. These findings provide an important basis for this study to explore the relationship between variables and formulate policies based on the characteristics of each country.

Table 1. Average GDP 1994-2023

Country	Average
Indonesia	2.410,20
Malaysia	7.558,74
Philippines	2.088,35
Brunei Darussalam	30.031,70
Thailand	4.433,20
Cambodia	1.050,56
Laos	1.208,15
Vietnam	1.680,42
Singapore	44.530,66

Source: Word Bank Processed, 2025

Based on the data, Singapore is in the highest position with an average GDP per capita of 44,530.66 USD, followed by Brunei Darussalam with 30,031.70 USD. Both countries show a level of prosperity that far exceeds other ASEAN countries, driven by an advanced economic structure and high investment levels, especially in the financial and energy sectors. Meanwhile, Malaysia and Thailand are in the middle position with an average of 7,558.74 USD and 4,433.20 USD, respectively. This position shows that both countries have succeeded in maintaining economic stability and carrying out sustainable industrialization. On the other hand, Indonesia and the Philippines have a lower average GDP per capita, namely 2,410.20 USD and 2,088.35 USD, respectively. Despite having a large population and abundant natural resource potential, both countries still face structural challenges in increasing productivity and equitable distribution of development results.

Given this complexity, this study aims to analyze the impact of renewable energy consumption, industrialization, and trade openness on carbon emissions by considering urbanization and economic growth simultaneously and to compare each country. Focusing on nine ASEAN countries provides space to compare countries with different levels of development, from advanced industrial countries such as Singapore and Malaysia to developing countries such as Laos and Cambodia. This approach fills a gap in the literature that has so far focused more on one or two dimensions (Kumar & Siregar, 2023).

Through a quantitative panel data approach and broad regional coverage, this study is expected to provide real contributions to the formulation of sustainable energy and industrial policies in ASEAN. The findings of this study can also be used as a basis for consideration in strengthening cross-country energy cooperation and encouraging investment in the clean energy sector, in line with the agenda of the ASEAN Plan of Action for Energy Cooperation (APAEC) 2021–2025 (Wong & Nurhadi, 2024).

Based on these dynamics, this study aims to comprehensively understand how renewable energy consumption, industrialization, and trade openness affect carbon emission levels in the ASEAN region, while also considering urbanization and economic growth as relevant factors. Not only focusing on the influence of each variable separately, this study also explores the differences in these influences between developing and developed countries in ASEAN, considering the variations in development stages, environmental policies, and technological capacity. By using panel data from nine countries for almost three decades, this approach is expected to provide a more complete and in-depth picture. The results of this study are intended to enrich academic discussions and become considerations for policymakers, especially in encouraging the transition to a more environmentally friendly energy and economic system, in line with regional commitments in the ASEAN Plan of Action for Energy Cooperation (APAEC) 2021–2025.

LITERATURE REVIEW

This study starts from the assumption that carbon emissions in ASEAN countries do not stand alone, but are influenced by various structural and policy factors. One of the main factors is renewable energy consumption. Logically, when a country increases the portion of energy use from renewable sources such as hydropower, solar, or wind, dependence on fossil fuels, which are the main contributors to emissions, will decrease. Therefore, renewable energy consumption is assumed to have a negative effect on carbon emissions. Countries that succeed in increasing their clean energy capacity are expected to be able to reduce emission levels significantly.

The model used in this study is based on a panel regression approach that maps the relationship between carbon emissions (CO_2) as the dependent variable, and five independent variables: renewable energy consumption (REC), industrialization (IDS), urbanization (URBA), economic growth (PE), and trade openness (TO). This model refers to the Environmental Kuznets Curve (EKC) theoretical framework, which states that the relationship between economic growth and environmental degradation is in the form of an inverted U-shaped curve (Grossman & Krueger, 1995), where in the early stages of growth will increase emissions, but at a certain stage it begins to decline due to the adoption of technology and environmental policies.

Renewable Energy Consumption

Renewable energy consumption is assumed to be able to reduce carbon emissions. The logic is simple: the higher the portion of energy that comes from clean sources such as hydropower, solar, and wind, the lower the dependence on fossil fuels. Susilowati et al. (2023) and Putri Buana & Hidayat (2024) show that renewable energy has a significant role in reducing emissions in ASEAN, especially when supported by adequate incentive policies and infrastructure. Tan et al. (2024) also emphasized that the main obstacles to the development of renewable energy in ASEAN lie in the high initial investment and limitations of local technology. Therefore, renewable energy is not only a technical solution, but also an issue of policy and institutional capacity. The energy transition theory explains that increasing the use of renewable energy will structurally reduce dependence on fossil fuels, thus having a negative impact on carbon emissions (IEA, 2023). In the ASEAN context, this theory is relevant because many countries are in the energy transition phase. For the trade openness variable, the Pollution Haven Hypothesis approach (Copeland & Taylor, 2004) states that developing countries that are open to international trade tend to attract pollution-intensive industries from developed countries. However, the Porter Hypothesis theory states the opposite: that openness can accelerate the diffusion of clean technology if supported by strong institutions.

Industrialization

Industrialization is often associated with increased emissions because the growth of the industrial sector usually drives large amounts of energy consumption. Lesmana et al. (2024) explain that the industrial sector in ASEAN is still very dependent on coal and oil, which contribute to emissions on a large scale. However, Adrian (2024) notes that the role of clean technology is starting to be seen in developing countries, which allows industrialization to go hand in hand with energy efficiency. In this context, the transition to low-carbon industry is an important key. Countries that are able to integrate energy efficiency into their industrial processes have the opportunity to reduce emissions without sacrificing economic growth. Meanwhile, industrialization and urbanization are explained through the structural economic approach and sustainable development theory, where industrialization increases economic output but also energy consumption, especially in countries with inadequate infrastructure and environmental regulations (Panayotou, 2003). On the other hand, industrialization is considered a factor that drives carbon emissions. When a country experiences industrial sector growth, it is usually

accompanied by an increase in production activities and energy consumption, especially fossil fuels. Therefore, this study assumes that industrialization has a positive relationship with carbon emissions, especially in countries that have not widely adopted environmentally friendly industrial technologies.

Urbanization

Urbanization is also closely related to carbon emissions. Population growth in urban areas demands energy availability for transportation, housing, and public facilities. Hossain et al. (2024) showed that large cities in Southeast Asia are experiencing great pressure on the environment due to uncontrolled urbanization. On the other hand, Anggara and Kaukab (2024) emphasized that the impact of urbanization is highly dependent on the quality of urban planning policies and the adoption of efficient technologies. Urbanization that is directed by smart city strategies and public transportation integration tends to produce lower emissions. Therefore, the effect of urbanization on emissions is highly dependent on the local policy context and city management capacity. Urbanization increases energy consumption and mobility, which in this model are considered as drivers of emissions, but the effects can be reduced through energy efficiency policies and smart city development.

Urbanization also cannot be ignored. The increase in the number of people living in cities causes an increase in energy demand for transportation, housing, and infrastructure. Without good management and energy efficiency policies, this urbanization process has the potential to significantly increase carbon emissions. Therefore, in this study, urbanization is assumed to have a positive impact on carbon emissions, although the effects can vary between countries depending on their city policies.

Economic Growth

Economic growth has a complex relationship with carbon emissions. On the one hand, growth can improve welfare. However, on the other hand, without a sustainable approach, growth also drives energy consumption and increases emissions. Zhang et al. (2023) found that in ASEAN, countries with high growth often show high carbon intensity, especially if they have not switched to clean energy. This indicates a possible trade-off between economic growth and environmental sustainability, which can only be minimized with a green economy approach. The concept of the Environmental Kuznets Curve (EKC) is also often used to explain that in the early stages of growth, emissions increase, but will decrease after income reaches a certain point along with improvements in technology and regulations. ASEAN countries that are still in the rapid growth stage generally experience increased emissions along with industrial expansion and consumption.

Then, economic growth is often associated with increased production and consumption activities, which ultimately also have an impact on increasing emissions. Although economic growth brings social and development benefits, without adequate green strategies, increasing national income can be an additional driver for increasing carbon emissions. Therefore, economic growth in this study is assumed to have a positive effect on emissions. Finally, trade openness is also assumed to affect carbon emissions. Countries that are increasingly open to international trade tend to increase their export and import volumes, which usually drive industrial growth and energy consumption. In such conditions, carbon emissions have the potential to increase. However, in some cases, trade openness can also support the transfer of clean technology from developed countries, which actually reduces emissions. Therefore, this variable is dynamic and the direction of its influence is very likely to differ from one country to another.

Trade Openness

Trade openness has a dual effect. On the one hand, as explained by the Heckscher-Ohlin theory, international trade can increase efficiency and economic growth. However, this openness can also increase emissions if export and import activities are still based on energy-intensive sectors. Candra (2024) and Dewi et al. (2025) show that the effect of trade on emissions is highly dependent on the character of the dominant economic sector and the country's ability to implement environmental regulations. In some cases, trade openness actually encourages the transfer of clean technology and improving environmental standards through integration into the global market. Therefore, the influence of trade openness is ambivalent and highly dependent on the institutional conditions of the country.

In the context of ASEAN development, trade openness and economic growth are two variables that have a close causal relationship. Based on neoclassical growth theory in an open economy, as developed in the extension of the Solow-Swan Model (Barro & Sala-i-Martin, 1995), trade openness allows a country to access wider markets, new technologies, and more efficient production inputs, all of which contribute to accelerated economic growth.

On the other hand, endogenous growth theory emphasizes that trade can encourage knowledge accumulation, innovation, and long-term productivity gains (Romer, 1990; Lucas, 1988). However, this relationship is also bidirectional: countries with high economic growth are usually more open to trade due to increased competitiveness and export capacity (Balassa, 1985; Frankel & Romer, 1999). Thus, in the empirical model of this study, trade openness and economic growth are not only explanatory variables for carbon emissions, but also influence each other in the dynamics of long-term development.

Related Research on ASEAN Countries

Research on renewable energy consumption, industrialization, and carbon emissions in ASEAN countries is still limited, although the importance of this topic is increasingly recognized. For example, research by Hossain et al. (2024) provides insight into the challenges faced by developing countries in ASEAN in managing energy consumption and its environmental impacts. Therefore, this study aims to fill the gap in the literature by analyzing the causal relationship between renewable energy consumption, industrialization, Trade Openness, urbanization, economic growth, and carbon emissions in nine ASEAN countries.

METHOD

Research Design

This study uses a quantitative design with a panel data analysis approach. This approach was chosen because it can describe the dynamic relationship between renewable energy consumption, industrialization, urbanization, trade openness, economic growth, and carbon emissions in the context of time and between ASEAN countries. This study aims to analyze the causal relationship between these variables using panel data of nine ASEAN countries during the period 1994-2023.

Population and Sample

The population in this study is nine ASEAN countries, namely Indonesia, Malaysia, the Philippines, Singapore, Thailand, Vietnam, Myanmar, Laos, and Cambodia. The research sample includes annual data during the period 1994 to 2023. The data used include carbon emissions (CO_2), renewable energy consumption, industrialization, urbanization, and economic growth for each country.

Research Variables

This study uses five main variables as follows:

1. Dependent Variable: Carbon emissions (CO_2) measured in metric tons of CO_2 per capita. This data is obtained from the World Bank and the International Energy Agency (IEA).
2. Independent Variables:
   a. Renewable Energy Consumption: Measured as the percentage of renewable energy contribution to the country's total energy consumption. This data is obtained from the IEA and national energy reports of ASEAN countries.
   b. Industrialization: Measured using data on the contribution of the industrial sector to the country's GDP. This data is taken from the World Bank.
   c. Urbanization: Measured by the percentage of the population living in urban areas. This data is also obtained from the World Bank.
   d. Economic Growth: Measured by the growth rate of GDP per capita, obtained from the World Bank.
   e. Trade Openness: Trade openness is measured using the ratio between the amount of exports and imports to Gross Domestic Product (GDP).

Econometric Models

Framework

$$CO2 = f(RE, IDS, URBA, PE, TO)$$

Where:
CO2: Carbon emissions (CO_2) per capita
RE: Renewable Energy Consumption
IDS: Industrial Sector Contribution
URBA: Percentage of population living in urban areas
PE: Economic Growth
TO: Trade Openness

D: Country Dummy

Equation Model

$$CO2 = \beta o + \beta 1\ RE + \beta 2\ IDS + \beta 3\ URBA + \beta 4\ PE + \beta 5\ TO + \gamma D\ (\gamma 1D1 + ... + \gamma 9D9) + \varepsilon$$

Where:
CO2: Carbon emissions (CO_2) per capita
RE: Renewable Energy Consumption
IDS: Industrial Sector Contribution
URBA: Percentage of population living in urban areas
PE: Economic Growth
TO: Trade Openness
D: 9 Country Dummy (D1, …, D9)
ε: Residual
βo: Intercep
β1, β2, …. B7: Variable Regression Coefficients
γ: Dummy Regression Coefficients (γ1 …, γ9)

Data Sources

The data used in this study were obtained from the following sources:

- World Bank: Data on GDP, economic growth, and urbanization.
- International Energy Agency (IEA): Data on renewable energy and fossil fuel consumption.
- United Nations: Data on carbon emissions.
- ASEAN State Bank: Data on industrialization and the contribution of the industrial sector to GDP.

Data Collection Techniques

The data used in this study are secondary data collected from various official sources, namely annual reports from the World Bank, IEA, and other public data relevant to the research topic. All data collected will be analyzed comprehensively to gain a deeper understanding of the impact of renewable energy consumption, industrialization, urbanization, and economic growth on carbon emissions.

Data Analysis Techniques

The data analysis technique in this study uses the panel data regression method (panel data regression analysis) to see the effect of renewable energy consumption, industrialization, urbanization, trade openness, economic growth, and trade openness on carbon emissions per capita in nine ASEAN countries during the period 1994–2023. The collected data will be analyzed using statistical software Eviews 10 and Eviews 12. Panel data regression is chosen because it can capture the characteristics of data across time (time series) and between countries (cross section) simultaneously and control heterogeneity between countries that are not individually observed and can reduce bias that arises from unobservable but time-invariant variables in each observation unit. To determine which model is most suitable for use in panel data modeling, model suitability tests are carried out using the Chow, Hausman, and Lagrange Multiplier tests. Normality, heteroscedasticity, autocorrelation, and multicollinearity tests are used to detect classical assumptions. To identify the best model that represents the relationship between variables, the Chow, Hausman, and Lagrange Multiplier tests are carried out. The test results show that the Fixed Effect Model (FEM) is most suitable for developing countries, while the Common Effect Model (CEM) is used for developed countries. This reflects the significant heterogeneity among developing ASEAN countries, while developed countries have more similarities in the context of the variables analyzed.

RESULTS AND DISCUSSION

Developed Countries and Developing Countries

Lagrange Multiplier (LM) Tests

Table 2. Lagrange Multiplier Tests for Random Effects

Test Method	Developed countries

	Cross-section Hypothesis	**Time Hypothesis**	**Combined (Both)**
Breusch-Pagan	337.2373 (0.0000)	4.845261 (0.0277)	342.0825 (0.0000)
Honda	18.36402 (0.0000)	-2.201195 (0.9861)	11.42884 (0.0000)
King-Wu	18.36402 (0.0000)	-2.201195 (0.9861)	15.26948 (0.0000)
Standardized Honda	27.50447 (0.0000)	-2.102457 (0.9822)	9.238292 (0.0000)
Standardized King-Wu	27.50447 (0.0000)	-2.102457 (0.9822)	16.30637 (0.0000)
Gourieroux, et al.	--	--	337.2373 (0.0000)

Source: Data processed by Eviews (2025)

Based on the data, it shows that prob. 0.00 < 0.05, then the data shows that it is included in the Random Effect Model because REM models the variation between cross-sections or time as a random effect that is normally distributed.

Hausman Test Trial

Table 3. Hausman Test

Test Summary	Chi-Sq. Statistic	Chi-Sq. d.f.	Prob.
Cross-section random	32.359814	5	0.0000

Source: Data processed by Eviews (2025)

Common Effect Model

Tabel 4. Common Effect Model

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	6097.556	92135.51	0.066180	0.9473
GDP	3.228613	1.541741	2.094134	0.0373
RE	-2262.336	724.1226	-3.124245	0.0020
URBA	0.485758	0.751260	0.646591	0.5185
INDUS	5611.833	1785.953	3.142206	0.0019
TO	733.1354	225.4996	3.251160	0.0013
DUMMY	-533256.0	67283.81	-7.925473	0.0000

Source: Data processed by Eviews (2025)

Random Effect Model

Table 5. Random Effect Model

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	185210.7	88942.17	2.082373	0.0384
GDP	2.062931	1.173832	1.757433	0.080

RE	-2628.539	680.8661	-3.860582	1 0.000
URBA	1.599838	0.598581	2.672715	1 0.008
INDUS	180.1084	1792.226	0.100494	0 0.920
TO	711.3943	254.9573	2.790248	0 0.005
DUMMY	-449729.9	84336.23	-5.332582	7 0.000

0

Source: Data processed by Eviews (2025)

Classical Assumption Test Results

Normality Test

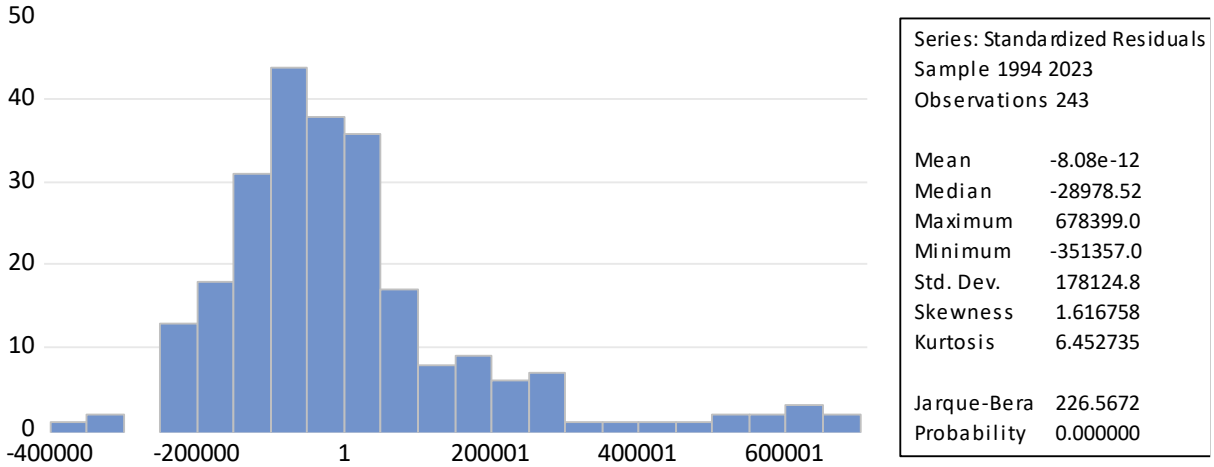


Figure 2.
Normality Test

Source: Data processed by Eviews (2025)

Multicollinearity Test

Table 6. Multicollinearity Test

Variable	GDP	RE	URBA	INDUS	TO
GDP	1.000	-0.573	-0.109	0.207	0.637
RE	-0.573	1.000	-0.294	-0.518	-0.455
URBA	-0.109	-0.294	1.000	0.635	-0.413
INDUS	0.207	-0.518	0.635	1.000	-0.188
TO	0.637	-0.455	-0.413	-0.188	1.000

Source: Data processed by Eviews (2025)

Based on the results of the correlation test between independent variables in the table above, there is no strong indication of multicollinearity. In general, the correlation between variables is in the low to moderate range. For example, the correlation between the variables urbanization (URBA) and industrialization (INDUS) is 0.635, and between trade openness (TO) and gross domestic product (GDP) is 0.637. Although these values indicate a

fairly close relationship, both are still below the general threshold considered to be at risk of causing multicollinearity, which is ±0.8. In addition, the correlation between other variables such as renewable energy (RE) and urbanization (URBA), as well as RE and INDUS are also below 0.6, so they do not indicate a relationship that is too strong. Thus, the results of this correlation indicate that the independent variables in the model are relatively not experiencing significant multicollinearity problems. However, to ensure more accuracy, it is recommended to carry out further testing using the Variance Inflation Factor (VIF) in order to detect multicollinearity quantitatively and more precisely.

Impact of Renewable Energy Consumption on Carbon Emissions

Based on the results of the Common Effect Model (CEM) and Random Effect Model (REM) regression, renewable energy (RE) consumption has a significant negative effect on carbon emissions. In the CEM model, the RE coefficient value is -2262.336 with a significance level of p = 0.0020, while in the REM model, the RE coefficient value is -2628.539 with p = 0.0001. This means that a 1 unit increase in the proportion of renewable energy can significantly reduce carbon emissions. This finding is consistent with the energy transition theory which states that increasing the use of clean energy will reduce dependence on fossil fuels. Laos and the Philippines are examples of ASEAN countries that have succeeded in optimizing renewable energy to reduce emissions, especially through hydroelectric and solar power plants.

Impact of Industrialization on Carbon Emissions

In the CEM model, the industrialization coefficient (INDUS) was recorded at 5611.833 with p = 0.0019, indicating a significant positive effect on carbon emissions. Meanwhile, in the REM model, the INDUS coefficient was 180.1084, but not significant (p = 0.9200). This indicates that in the group of developed countries (analyzed by CEM), industrialization is more strongly driving increased emissions than in developing countries. Countries such as Vietnam and Thailand have experienced massive industrial expansion in the manufacturing and electronics sectors, which have a direct impact on the high consumption of fossil-based energy.

Impact of Urbanization on Carbon Emissions

Urbanization (URBA) shows an insignificant effect in the CEM model (coefficient = 0.485758, p = 0.5185) but is significant in the REM model with a coefficient of 1.599838 and p = 0.0080. This shows that in the context of developing countries, increasing urbanization has a significant impact on carbon emissions. This condition can be explained by the weak urban governance and green infrastructure in countries such as Indonesia and the Philippines, where urbanization often occurs without proper planning, causing a surge in energy and transportation demand.

Impact of Economic Growth on Carbon Emissions

The GDP variable (growth per capita) shows a positive and significant effect in the CEM model with a coefficient of 3.228613 and p = 0.0373. In the REM model, the GDP coefficient is 2.062931 with p = 0.0801, which means it is close to significant. This strengthens the argument of the Environmental Kuznets Curve (EKC), that in the early phase of economic growth, emissions tend to increase along with industrialization and energy consumption. ASEAN countries such as Indonesia, Vietnam, and Laos show this pattern, where economic growth has not been accompanied by energy efficiency or the adoption of clean technology.

Impact of Trade Openness on Carbon Emissions

Trade Openness (TO) in both models shows a significant positive effect on carbon emissions. In the CEM model, the TO coefficient is 733.1354 (p = 0.0013), while in the REM model it is 711.3943 (p = 0.0057). This indicates that trade openness encourages increased industrial activity and cross-border transportation, which in turn increases energy consumption and carbon emissions. However, in the long run, trade can also function as a channel for environmentally friendly technology transfer, depending on the strength of each country's institutional and environmental regulations.

Impact of Renewable Energy Consumption, Industrialization, Urbanization and Trade Openness on Carbon Emissions

The estimation results show that only renewable energy (RE) consumption variables consistently have a significant negative effect on emissions, while industrialization, economic growth, urbanization (in developing countries), and trade openness tend to increase carbon emissions. This indicates structural challenges in the

economic development process of ASEAN countries. Policies that support clean energy transformation, industrial efficiency, and green city planning need to be adopted across sectors. In addition, the establishment of a regional framework within ASEAN to strengthen energy transition cooperation is an important strategy to ensure that economic growth does not conflict with carbon emission reduction targets.

CONCLUSION

The results of this study highlight the critical role of renewable energy consumption in reducing carbon emissions across ASEAN countries, with a consistently significant negative impact observed in both regression models. This underlines the importance of accelerating the transition to clean energy as a central pillar in climate mitigation strategies. However, the findings also indicate that industrialization, urbanization, economic growth, and trade openness are associated with rising emissions, especially in developing countries with less environmental regulation and technological capacity.

These dynamics reflect the complex trade-offs faced by ASEAN countries between economic development and environmental sustainability. While growth and globalization bring opportunities, they also present significant environmental risks when not managed with strong institutional frameworks and green policies. To ensure long-term sustainability, ASEAN governments must implement integrated policies that promote energy efficiency, low-carbon industrial development, sustainable urban planning, and environmentally responsible trade practices.

Regional collaboration through mechanisms like the APAEC and the ASEAN Economic Community (AEC) should be strengthened to share best practices, mobilize funding, and transfer green technologies. Ultimately, this research provides timely evidence and policy implications that can guide ASEAN's path toward a balanced development model one that not only fosters economic growth but also ensures environmental preservation for future generations.

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