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Analysis of Carbon Emissions in ASEAN Manufacturing: Input-Output and Panel Data Approach

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Abstract

This research aims to identify the leading sectors in four ASEAN countries and analyze the influence of production in these sectors and the consumption of renewable energy on carbon dioxide emissions in these countries. The analytical methods used include the analysis of inter-sector linkages and identifying leading sectors using input-output tables, followed by further analysis with panel data regression. The results indicate that while the leading sectors vary among the four countries, the manufacturing sector predominantly leads. Additionally, GDP in the manufacturing sector significantly positively affects carbon dioxide emissions in the four ASEAN countries, namely Indonesia, Malaysia, Thailand, and Vietnam, but carbon emissions are significantly impacted negatively by the usage of renewable energy. These results highlight the necessity for ASEAN countries to adopt balanced development strategies that promote economic growth while lowering environmental consequences through clean technology, energy efficiency, and renewable energy initiatives.

Keywords: ASEAN, Carbon Emissions, Input-Output Table, Manufacturing Sector, Panel Regression

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INTRODUCTION

Climate change is an international issue that currently commands the focus of countries worldwide due to its severe and complex impacts on environmental quality. From an environmental perspective, several studies state climate change leads to increased temperatures and sea levels, polar ice melting, and overall global warming (Amanda, 2023). A report published by The Lancet Countdown in 2022 highlights that climate change exacerbates the suffering of those already affected by COVID-19 and the cost of living and energy crises. Heat exposure led to the loss of 470 billion working hours globally in 2021. Additionally, extreme weather events caused damages amounting to $253 billion, particularly in countries with a low Human Development Index (HDI) where losses are often uninsured. The worsening climate quality also negatively impacts public health and disrupts food production due to crop failures (The Lancet Countdown on Health and Climate Change, 2022).

Research by Ilham (2018) indicates that Gross Domestic Product (GDP) and energy consumption positively affect environmental degradation. There is also a positive relationship between carbon dioxide emissions and economic development. Ghosh (2010) supports this in his research, stating that a short-term causal relationship exists between carbon dioxide emissions and economic growth. These findings align with Kuznets' theory that high economic growth often coincides with environmental damage. Numerous studies suggest that the leading sectors of a country are the primary contributors to gas emissions. However, these sectors are crucial for economic progress as they not only boost GDP but also drive other sectors through the demand for raw materials, services, and technological innovation (Unido, 2020).

Given the complex impact of declining environmental quality, countries strive not only for economic development but also for a clean environment. This is evidenced by the global commitment to the Sustainable Development Goals (SDGs). Among the 17 SDGs, two specifically address environmental concerns: Goal 7 (Clean and Affordable Energy) and Goal 13 (Climate Action).

ASEAN is a regional organization comprising Southeast Asian countries. Over the past 45 years, ASEAN has transformed into a significant multilateral association. Since World War II, the ASEAN economy has grown and developed, even as other regions struggled with the 2008 global recession (Kurlantzick, 2012). Figure 1 shows that ASEAN's GDP growth has been above the global average since 1990, except in 1998 and from 2021 to 2022 due to economic crises and the time required for recovery post-COVID-19, considering that most ASEAN member countries are developing nations. Despite these challenges, ASEAN remains one of the world's fastest-growing economic regions (ADB, 2023).

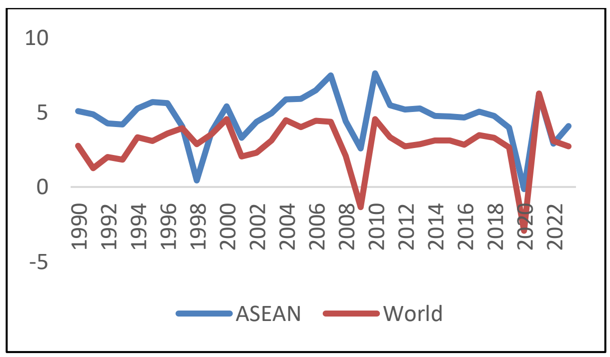

Figure 1. ASEAN and world GDP growth
Source: World Bank, 2024

This rapid economic growth cannot be separated from the crucial role of the economic sector in each ASEAN country. According to ASEAN publication data, the economy is generally divided into three main sectors: the primary sector, which includes agriculture, mining, and quarrying industries; the secondary sector, which consists of the manufacturing, electricity, gas, air supply industries, and construction; and the tertiary sector, which comprises the service industry. Among these sectors, the three with the largest contributions to the ASEAN economy in 2022 are manufacturing with a percentage of 21.2%, wholesale and retail trade and repair of motor vehicles and motorcycles with a percentage of 14.7%, and the public service and other services sector with a percentage of 10.3%. For decades, the manufacturing sector has acted as a leading sector with a contribution consistently above 20%. When the contribution of a sector is greater, the potential for that sector to become a leading sector also increases. Therefore, the stability of the leading sector needs careful consideration.

However, despite ASEAN's favorable economic growth, this growth is also accompanied by an increase in carbon dioxide emissions in the region. High levels of carbon dioxide lead to temperature and climate changes. Figure 2 shows that carbon emissions in the ASEAN region have continued to rise from 1990 to 2020. Increased human activity results in higher concentrations of carbon dioxide and global warming, causing significant changes in the earth's temperature and triggering various environmental disturbances (Kabir et al., 2023). Given these facts, economic development in ASEAN countries must aim to create balanced policies that promote economic growth while ensuring environmental sustainability.

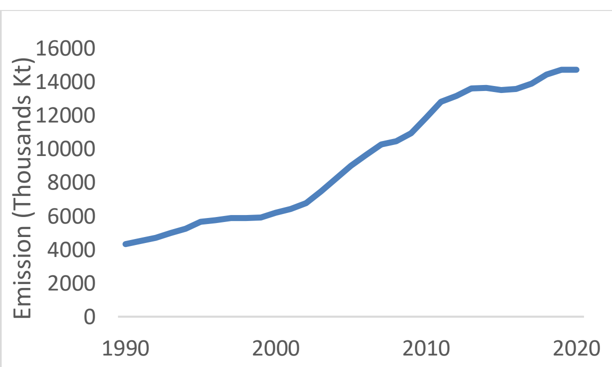

Figure 2. ASEAN carbon emissions
Source: World Bank, 2024

ASEAN has participated in several global efforts to improve environmental quality, one of which is the signing of the Paris Agreement. The Paris Agreement is a legally binding international agreement aimed at combating climate change. In this agreement, each country is called upon to keep the increase in global average temperature well below 2 degrees Celsius and to limit the temperature increase to 1.5 degrees Celsius above pre-industrial levels. The Paris Agreement sets a target of reducing greenhouse gas emissions by 43% by 2030.

One practical application of efforts to implement the Paris Agreement is through the adoption of renewable energy (ACE, 2017). ASEAN member countries have also increased the percentage of renewable energy use in their overall energy supply (Vo. DH, & Vo. AT, 2021). Research conducted by Can Sener (2018) explains that renewable energy can reduce carbon dioxide emissions, thereby preventing negative environmental impacts. Additionally, the advantages of renewable energy include increased energy supply security and the stimulation of sustainable economic growth.

Based on the description above, this research aims to determine the leading sectors in the ASEAN region and analyze the influence of production in these sectors and the consumption of renewable energy on carbon dioxide emissions in the ASEAN region. This research uses a sample of four ASEAN countries: Indonesia, Thailand, Malaysia, and Vietnam, which are the largest contributors to emissions in the ASEAN region (Southeast Asia Green Economy, 2023)

RESEARCH METHODS

The Kuznets curve is an inverted U-shaped curve regarding the relationship between income inequality and economic growth. This curve has an assumption that high economic growth is in line with environmental damage (Kuznets, 1955). This inverted U curve shows that after exceeding a certain level of GDP per capita, the trend of environmental degradation will reverse so that higher GDP per capita leads to environmental recovery bringing the environment back to its initial state during economic development (Miswa & Kartiasih, 2025; Yao et al., 2019).

Input-output model was introduced by Wassily W. Leontief in 1951 where the model was a development of the technique used by Francois Quesnay (1694-1774) in his book Tableau Economique. This input-output model is used to see inter-industry relationships understand the interrelationships and complexity of the economy and maintain a balanced condition of supply and demand (Hayuningtyas et al., 2024; Sari et al., 2024; Taridipa et al., 2024).

The relationship between the economy and carbon dioxide emissions has been widely studied by experts. According to the Kuznets curve theory, economic growth initially triggers a decline in environmental quality But beyond a certain point, environmental quality improves as the economy continues to grow. This assumption is known as the Environmental Kuznets Curve (EKC) hypothesis.

Table 1. Example Input-Output Table (3 Sectors)

Input Structure	**Output Allocation**	**Intermediate Request**			**Final Request**	**Provision**	
		Sector 1	Sector 2	Sector 3		Import	Output Number
Intermediate Input			Quadrant I			Quadrant II	
Sector I		z11	z12	z13	y1	ml	x1
Sector 2		z21	z22	z23	y2	m2	x2
Sector 3		z31	z32	z33	y3	m3	x3
			Quadrant III				
Primary Input		vl	v2	v3			

Source: Data processed, 2024

Testing this hypothesis has been conducted in many countries, but so far, the results have not reached a conclusive consensus (Pribadi & Kartiasih, 2020; Kartiasih & Setiawan, 2020). Research by Idris & Sari (2022) on proving the EKC curve in Indonesia using GDP and the Environmental Quality Index with the multiple linear regression method shows that the EKC hypothesis applies to several Indonesian islands such as Sumatra, Sulawesi, and Kalimantan. However, it does not apply to the islands of Java and Bali, indicating that, in general, the EKC hypothesis does not hold for Indonesia. Meanwhile, Rambeli et al. (2021) examined the relationship between energy consumption, GDP, urbanization, trade openness, and financial development on carbon dioxide emissions using the ARDL method in Singapore and Malaysia.

The results show that energy consumption has a significant positive effect in both countries. The EKC hypothesis holds, indicating a U-shaped relationship between carbon dioxide emissions and economic growth. Research by Setiawan & Primandhana (2022) discusses the relationship between the GRDP of the agricultural, mining and quarrying, processing industry, and transportation and warehousing sectors on EQI (Environmental Quality Index) using panel data regression in 34 provinces in Indonesia from 2014 to 2020. It shows that the GRDP of the agricultural and processing industry sectors has a significant positive relationship with EQI while mining GRDP has a significant negative effect. The transportation and warehousing GRDP has no significant effect on EQI.

Table 2. Operational Definition of Variables

Variable	Symbol	Indicator	Unit	Source
CO_2 carbon emissions	CE	The amount of CO_2 gas emissions originating from long cycle biomass burning	Mega ton (billion kg)	World Bank
Manufacturing sector GDP	Manuf	Added value from the manufacturing sector which refers to industries included in ISIC division 10-33 with data in constant prices 2015	Billion USD	World Bank
Contribution of renewable energy consumption	Energy	Total contribution of renewable energy consumption to overall energy consumption	Percent	World Bank

Source: World Bank, 2024

Research by Vo & Vo (2021) discusses the relationship between renewable energy consumption, population growth, and economic growth on carbon dioxide emissions using the ARDL VECM model with observations of 7 ASEAN member countries for the period 1980 to 2016. The results show that renewable energy consumption has the potential to reduce carbon dioxide emissions, but its impact depends on a country's level of economic development. In low-income countries, increasing the use of renewable energy can sometimes still increase CO_2 emissions, while in high-income countries, renewable energy use tends to significantly reduce CO_2 emissions.

This research uses data from the 2016 Input Output (IO) Table for four ASEAN countries, namely Indonesia, Thailand, Malaysia, and Vietnam, sourced from the website worldmrio.com. The data consists of 26 industrial sectors. The variables used are input-output and final demand from each country. Additionally, the advanced analysis used in this study (panel data regression) requires other variables, namely the amount of CO_2 carbon emissions, GDP of the manufacturing sector, and the contribution of renewable energy consumption. The period of the variables used in this study is from 1990 to 2020.

The sectors contained in the input output table can be seen whether they influence each other or not. Sectors that influence each other are usually referred to as intersectoral linkages where one sector can produce intermediate inputs for other sectors to produce output from that sector. Furthermore, we can find out which sectors are the leading sectors by calculating backward linkage and forward linkage using a multiplier matrix.

The linkages between these sectors can be used to see the extent to which development in one economic sector influences or is influenced by development in other sectors. The results of this analysis are then used as a tool for developing development priorities. These sectors are further divided into key sectors and non-key sectors. This classification measures backward linkages (demand pull concept) and forward linkages (supply push concept) (Miller & Blair, 2022).

$$BL_j = \sum_{i=1}^{n} b_{ij}$$

$$FL_i = \sum_{j=1}^{n} b_{ij}$$

Where BL_j is the backward linkage of sector j, FLi is the forward linkage of sector i, and bij is the element of the inverse Leontief matrix . The Leontief Matrix is an output multiplier matrix which is a function that connects final demand with production levels. The matrix can estimate the impact of changes in exogenous variables in final demand on changes in output.

BPS (2025) provides a term for measuring the backward linkages of a sector, indicated by the Spread Power Index (Power of Dispersion Index) and the measure of forward linkages shown by the Sensitivity Power Index (Index of Sensitivity). The formula for each index is as follows

$$Power\ Dispersion = (\sum_{i=1}^{n} b_{ij})/(\frac{1}{n}(\sum_{i}\sum_{j} b_{ij}))$$

$$Index\ of\ Sensitivit = (\sum_{j=1}^{n} b_{ij})/(\frac{1}{n}(\sum_{i}\sum_{j} b_{ij}))$$

If the Power of Dispersion Index value is > 1, it indicates that an increase in one unit of final consumption in sector j will increase economic activity above the average increase due to an additional unit of final consumption in other sectors. Furthermore, an Index of Sensitivity value > 1 means that an increase in one unit of production in sector I will cause an increase in economic activity above the average increase due to additional units of production in other sectors. So, if a sector has more than one Power of Dispersion Index and Index of Sensitivity value, it is categorized as a key sector or leading sector.

Further analysis in this research uses panel data regression to see the relationship between leading sectors in each country and the amount of carbon emissions. The regression estimation model for this research is

$$CE_{it} = \beta_0 + \beta_1 Manuf_{it} + \beta_2 Energy_{it} + \epsilon_{it}$$

Where CE is Total CO2 carbon emissions from the manufacturing sector; $Manuf$ is GDP of the manufacturing sector; and $Energy$ is the amount of consumption of renewable energy sources. The panel data regression model has three forms, namely the Common Effect Model (CEM), Fixed Effect Model (FEM) , and Random Effect Model (REM). The CEM model assumes that the expected value of the error is zero, the variance is constant, and there is no autocorrelation between the independent variables. CEM model is

$$Yit = \beta_0 + \beta_1 X1_{it} + \beta_2 X2_{it} + \cdots + \beta_p Xp_{it} + \epsilon_{it}$$

Where i is 1, 2,..N and t is 1, 2..T. In the FEM model there is a correlation between μ_i and the independent variable (X). To see differences between individuals can be seen from the intercept. FEM model is

$$Yit = \alpha + \beta_1 X1_{it} + \beta_2 X2_{it} + \cdots + \beta_p Xp_{it} + \mu_{it} + v_{it}$$

$$Y_{it} = (\alpha + \mu_{it}) + \beta_1 X1_{it} + \cdots + \beta_p Xp_{it} + (\mu_{it} + v_{it})$$

Where i = 1,2,...,N ; t = 1,2,...T and μ_i is fixed. In this model, there is no autocorrelation between μ_i and the independent variable (X) and differences between individuals can be seen from the difference in intercepts. REM model is

$$Y_{it} = \alpha + \beta_1 X1_{it} + \beta_2 X2_{it} + \cdots + \beta_p Xp_{it} + (\mu_{it} + v_{it})$$

Where i is 1,2,...,N ; t is 1,2,...T and μ_i is random. The three models previously described must be tested first so that it can be identified which model is suitable for the data in this study. The hypothesis in Chow test is

$$H_o: \alpha_1 = \alpha_2 = \alpha_3 = \cdots = \alpha_{10} = \alpha$$
$$H_1 is\ at\ least\ one\ \alpha is\ significantly\ different$$

The test statistics used are

$$F_{obs} = \frac{R^2FE - \left(\frac{R^2Pooled}{n-1}\right)}{\frac{1-R^2FE}{nT-n-k}} \sim F((n-1);(nT-n-k))$$

If F obs is greater than F table or the p-value is smaller than the significance level, then the decision is Reject Ho which means the Fixed Effect Model is more appropriate to use. The Hausman test are

$$H_0: E(X_{it}) = 0$$
$$H_1: E(X_{it}) \neq 0$$

If the p-value is smaller than the significance level, then the decision is Reject Ho, which means *the Fixed Effect Model* is more appropriate to use. The BP-LM test are

$$H_0: \sigma_\mu^2 = 0$$
$$H_1: \sigma_\mu^2 \neq 0$$

The test statistics used are (greene, 2012)

$$LM = \frac{N(T)}{2(T-1)}\left[\frac{\sum_{i=1}^{N} e_{it}^2}{\sum_{i=1}^{N}\sum_{i=1}^{T} e_{it}^2}\right] \sim \chi_1^2$$

Information N is cross section unit; T is time series periods ; e_{it} is residual of inidividual i in period t. After testing the best model, in regression, assumption testing needs to be carried out to avoid biased or invalid parameter estimates. Multicollinearity checking is used to see how strong the correlation is between independent variables in a model. Checking multicollinearity uses the Variance Inflation Factor (VIF). If the VIF of a variable is more than 10 then the variable is indicated to have a strong relationship with other variables.

The homoscedasticity test is used to see whether the variance of the residuals of one observation and other observations is different or similar (Ghozali, 2018). The test statistic used is the variance-covariance statistic. Using the Lagrange Multiplier formula with a c hi-square distribution with N-1 degrees of freedom, the decision is to reject Ho if the test statistic is greater than the table statistic or the p-value is smaller than the significance level. The hypothesis used in this test are

$$H_0: \sigma_i^2 = \sigma^2$$
$$H_1: \sigma_i^2 = \sigma_j^2$$

The autocorrelation test is used to see whether there is a correlation between variables in the model with changes in time. In other words, whether an observation is influenced by previous observations. In time series data, this is important because there is usually a correlation between observations from time to time. The hypothesis used in this test are

$H_0: There\ is\ no\ autocorrelation\ in\ the\ model$
$H_1: There\ is\ autocorrelation\ in\ the\ model$

The statistics used in this test is the Durbin-Watson test with the formula

$$d_{pd} = (\sum_{i=1}^{N}\sum_{t=2}^{T}\left(e_{it} - e_{i,t-1}\right)^2)\,/\left(\sum_{i=1}^{N}\sum_{t=2}^{T}e_{it}^2\right)$$

The decision rule for the autocorrelation test with the DW-test is to compare the DW-test values with the DW-table. If the dU value < DW-test < 4-dU then the decision is Fail to Reject Ho with the conclusion that there is no autocorrelation in the regression model.

The normality test is used to see whether the distribution of the residuals in the regression model is normally distributed or not. For good model estimation, normality is needed in forming the regression model. The hypothesis used in this test are

$H_0: \epsilon_i \sim N(\mu, \sigma^2)$
$H_1: \epsilon_i \nsim N(\mu, \sigma^2)$

In this research, the test statistic used is the Jarque-Bera Test with the formula

$$JB = \frac{n}{6}\left(S^2 + \frac{1}{4}(K-3)^2\right); S = \frac{\mu^3}{\sigma^3} and\ K = \frac{\mu^4}{\sigma^4}$$

The model feasibility test was carried out to identify whether the regression model formed was suitable or not to explain the influence of the independent variable on the dependent variable (Riswan, 2019). The model feasibility test consists of hypothesis testing and analysis of the coefficient of determination. The hypothesis used in the simultaneous test is

$H_0: \beta_1 = \beta_2 = 0$
$H_1: at\ least\ one\ \beta_i \neq 0$

The test statistic is the F test statistic which is compared with the F-table. If the F-calculated value is greater than the F-table or the p-value is smaller than the significance level then the decision is Reject Ho which means the independent variables in the model together have a significant effect on the dependent variable. The hypothesis used in the partial test are

$H_0: \beta_i = 0, i = 1,2$
$H_1: \beta_i \neq 0, i = 1,2$

The test statistic used is the t test statistic which is compared with the t-table. If the calculated t-value is greater than the t-table or the p-value is smaller than the significance level then the decision is Reject Ho which means the independent variable in the model partially has a significant effect on the dependent variable

Coefficient of determination analysis is used to see how much the independent variables in the model explain variations in the value or changes in the value of the dependent variable. The coefficient of determination is symbolized as R square. The greater the value, it can be concluded that the independent variable used in the model is suitable because it can explain the value of the dependent variable in the model.

RESULTS AND DISCUSSION

Several industries in Indonesia have been recognized as leading industries, with both the Power of Dispersion Index and Index of

Sensitivity indices exceeding the value of 1 (see Figure 3). The leading industries in Indonesia include "Mining and Quarrying" and "Wood and Paper". These industries have a large impact on the input requirements for other economic activities, as indicated by their high Dispersion Power Index. Additionally, their high degree of Sensitivity Index suggests that the growth of output in other economic sectors is significantly influenced by their output.

To promote sustained regional economic development, several industries are essential. In 2016, the wood and paper industry contributed significantly to Indonesia's economic expansion. In 2016, the wood and paper industry contributed significantly to Indonesia's economic expansion.

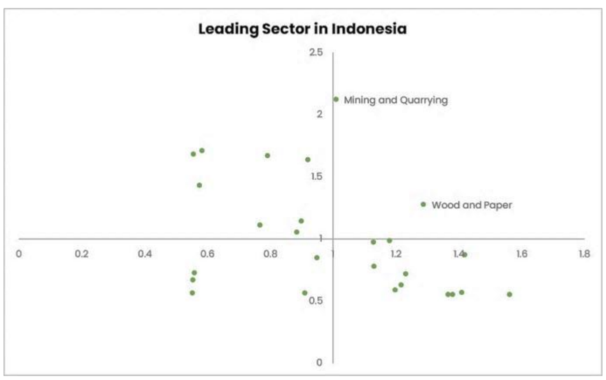

Figure 3. Distribution of Power of Dispersion Index, Index of Sensitivity, and Leading Sector Values in Indonesia
Source: Data processed, 2024

With the forestry industry's robust forward and backward links supporting economic development, it made a substantial contribution. With an estimated 120 million hectares of forest area, Indonesia boasts enormous forest resources, making the forestry sector a crucial part of the country's economy (Sahara, 2022).

According to Figure 4, there is only one dominant industry in Malaysia, as shown by the Index of Sensitivity and Power of Dispersion Index both being above 1. The "Metal Products" sector is this one. Its large Power of Dispersion Index indicates that it has a major impact on other economic sectors' input requirements. Its high Index of Sensitivity further suggests that its output has a major influence on the growth of output in other economic sectors.

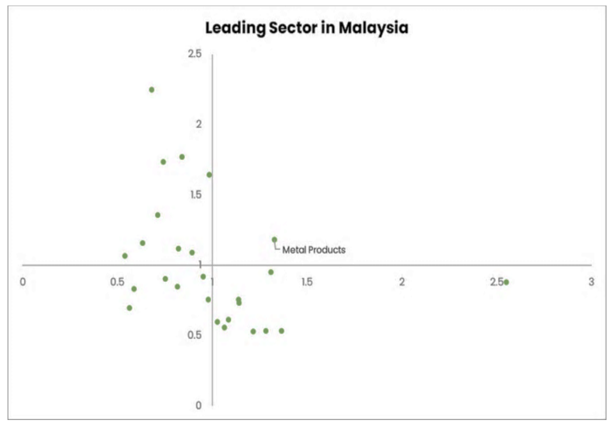

Figure 4. Distribution of Malaysia's Power of Dispersion Index, Index of Sensitivity, and Leading Sector Values
Source: Data processed, 2024

To promote sustained regional economic development, several industries are essential. The metal products industry is important to Malaysia's economy, especially in the manufacturing sector, which generates over 40% of the nation's GDP, even if it was not specifically identified as a major driver of the country's economic growth in 2016. The metal industry contributed RM22.2 billion to Malaysia's GDP in 2020, demonstrating the significant increase this sector has enjoyed (Ministry of Investment, Trade, and Industry of Malaysia, 2023).

According to Figure 5, several Thai industries are categorized as leading industries as their Index of Sensitivity and Power of Dispersion Index are both higher than 1. Sectors such as

"Electrical Equipment and Machinery," "Electricity, Gas, and Water," "Metal Products," and "Other Manufacturing" are examples of this type of business. These industries have a high Power of Dispersion Index, which suggests that they have a big impact on other economic sectors' input needs. These industries also have a high Index of Sensitivity, which indicates that the growth of their output has a significant influence on the development of output in other economic sectors.

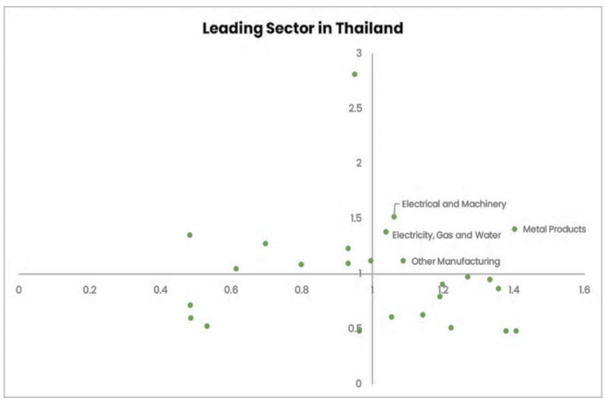

Figure 5. Distribution of Thailand's Power of Dispersion Index, Index of Sensitivity, and Leading Sector Values
Source: Data processed, 2024

To promote sustainable economic development in the Thai region, several industries are essential. According to Sangiam's (2015) research, the majority of workers are employed in the manufacturing of electronic components, textiles, metals, and agriculture. Thailand is the largest exporter of computers and computer components in ASEAN and the second-largest producer of Hard Disk Drives (HDDs) after China (Sriring, 2015).

Based on the findings presented in Figure 6, various industries within Vietnam, such as "Electrical Equipment and Machinery", "Electricity, Gas and Water", "Transportation Equipment", "Non-Metal Oil, Chemical and Mineral Products", and "Metal Products", are identified as prominent sectors due to their classification as Leading Sectors.

This classification is attributed to these sectors exhibiting a Power of Dispersion Index and Index of Sensitivity that surpass 1. These sectors demonstrate a notable Power of Dispersion Index, signifying their significant impact on the input requirements of other economic sectors.

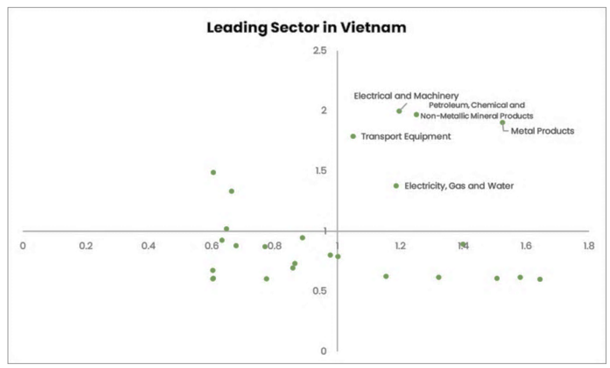

Figure 6. Distribution of Vietnam's Power of Dispersion Index, Index of Sensitivity, and Leading Sector Values
Source: Data processed, 2024

Based on the data presented in table 3, disparities in the predominant sectors among nations within this particular geographical area are evident. In Indonesia, the primary sectors are Mining & Quarrying and Wood & Paper industries. Conversely, in Malaysia, the dominant sector is Metal Products. Furthermore, they also display a high Index of Sensitivity, indicating that their production significantly influences the output development of other economic sectors.Consequently, these sectors play a crucial role in facilitating sustainable economic growth within Vietnam.

Table 3. List of Leading Sectors for Each Country

Sector	Indonesia	Malaysia	Thailand	Vietnam
Wood & Paper*	Superior	Not Featured	Not Featured	Not Featured
Petroleum Products, Chemicals & Non-Metallic Minerals*	Not Featured	Not Featured	Not Featured	Superior
Metal Products*	Not Featured	Superior	Superior	Superior
Electrical Equipment & Machinery*	Not Featured	Not Featured	Superior	Superior
Transportation Equipment*	Not Featured	Not Featured	Not Featured	Superior
Other Manufacturing*	Not Featured	Not Featured	Superior	Not Featured
Procurement of Electricity, Gas & Water	Not Featured	Not Featured	Superior	Superior

Note: *) Manufacturing Sector
Source: Data processed, 2024

In contrast, in Thailand, the prevailing sectors encompass Electrical Equipment & Machinery; Procurement of Electricity, Gas & Water; Metal Products; and Other Manufacturing. Similarly, in Vietnam, the key sectors comprise Electrical Equipment & Machinery; Procurement of Electricity, Gas & Water; Transportation Equipment; Petroleum Products, Non-Metal Chemicals & Minerals, and Metal Products.

The industrial sectors utilized in Eora26 exhibit a correlation with the sectors encompassed in ISIC. Upon scrutinizing the predominant sectors in the aforementioned four ASEAN countries, it becomes apparent that each nation possesses a substantial manufacturing sector. This suggests that the manufacturing domain plays a pivotal role in driving economic advancement by emerging as the leading sector in these ASEAN nations. This observation aligns with research undertaken by KPMG International, which underscores the significance of the manufacturing sector in various ASEAN countries.

Table 4. CEM Parameter Estimation

Parameter	Estimated Value	t-statistics	p-value
c	35.649	5.0179	0.0000**
Manufacture	2.596	42.2176	0.0000**
Energy	-0.3424	-2.3072	0.0227**
F-statistics			923.4131
p-value			0.0000**
Adjusted R square			0.9375

Note: **) = significant at 5% alpha
Source: Data processed, 2024

Despite the economic advancement facilitated by these sectors, there are assertions that they could potentially lead to emissions.

Various studies, such as the one conducted by Setiawan & Primandhana (2022), have delved into the effects of the GRDP of the manufacturing sector on environmental conditions. Furthermore, Yusuf (2020) highlights that industrialization, characterized by the proliferation of manufacturing and industrial undertakings, stands as a major driver of greenhouse gas emissions.

Table 5. FEM Parameter Estimates

Parameter	Estimated Value	t-statistics	p-value
c	124.832	10.4138	0.0000**
Manufacture	2.187	27.0603	0.0000**
Energy	-2.434	-9.9662	0.0000**
F-statistics			1075.056
p-value			0.0000**
Adjusted R square			0.9776

Note: **) = significant at 5% alpha

Source: Data processed, 2024

This underscores the importance of further exploring how economic progress, particularly within the manufacturing sector, impacts the environment. Consequently, we undertook an analysis utilizing panel data regression to ascertain the influence of the development of this industrial sector on environmental aspects. The CEM model estimation results are displayed in Table 4. The FEM model estimation results are shown in Table 5.

Based on the findings derived from the EViews software, the outcomes of the model adequacy tests are presented in table 7. The outcomes of the Chow test indicate that the Fixed Effects Model (FEM) outperforms the Common Effects Model (CEM). In contrast, the results of both the Hausman test and BP-LM test suggest that the Random Effects Model (REM) is more suitable for analytical purposes compared to the FEM and CEM The REM model estimation results are shown in table 6.

Table 6. REM Parameter Estimation

Parameter	Estimated Value	t-statistics	p-value
c	117.926	5.3678	0.0000**
Manufacture	2.227	28.3089	0.0000**
Energy	-2.291	-9.6932	0.0000**
F-statistics			1260.538
p-value			0.0000**
Adjusted R square			0.9534

Source: Eviews (processed data);)** = significant at 5% alpha

Model selection is based on the results of the Chow, Hausman, and Breusch-Pagan Tests. The test results can be seen in table 7. Hence, the Random Effects model is deemed more appropriate for the subsequent stages of analysis. Within the Random Effects Model framework, the necessary assumption testing involves assessing residual normality and detecting multicollinearity.

Table 7. Selection of the best model

Test Type	p-value	Decision	Best Model Conclusion
Test Chow	0.0000**	Reject Ho	Fixed Effect Model
Hausman test	0.0592**	Failed to Reject Ho	Random Effect Model
BP-LM Test	0.0000**	Reject Ho	Random Effect Model

Note: **) = significant at 5% alpha

Source: Data processed, 2024

This is because the random effects model employs either Generalized Least Squares (GLS) or Feasible Generalized Least Squares (FGLS) estimation methods, which explicitly address the potential presence of simultaneous correlation and heteroscedasticity in the residuals. By utilizing GLS or FGLS, it is possible to rectify issues related to heteroscedasticity and autocorrelation during the estimation process, ensuring the efficiency of parameter estimation even in the presence of such problems.

Table 8. Residual normality test

Jarque Bera Score	p-value
10.4919	0.0053

Source: Data processed, 2024

Utilizing table 8 as a reference, it has been determined that the course of action adopted involves rejecting Ho, indicating a violation of the normality assumption. Nevertheless, by the findings of Gujarati and Por=ter (2008), the normality assumption holds less significance in datasets with a substantial number of observations. In instances where the sample size is large, the distribution of the sample closely resembles that of the population, typically following a normal distribution pattern. Thus, it is inferred that the data conforms to a normal distribution due to the large sample size.

Table 9. VIF value for each independent variable

Manufacturing GDP	Renewable Energy
2.0206	2.0205

Source: Data processed, 2024

This assumption explores the extent of the relationship among the independent variables in the equation. The representation of this relationship is denoted by the Variance Inflation Factor (VIF) value, which is displayed in table 9 above. According to the data presented in table 9, it has been observed that the Variance Inflation Factor (VIF) for every independent variable falls below the threshold of 10.

This observation suggests the absence of a significant relationship between the Manufacturing GDP variable and Renewable Energy. Stated differently, the assumption of non-multicollinearity has been satisfied. Based on the results of determining the best model, the following random effect model is used is

$$Y_{it} = 117.926 + 2.227X1_{it} - 2.291X2_{it} + (\mu_{it} + v_{it})$$

with error values (μ_{it}) for each country as presented in table 10

Table 10. Cross-section Random Effect

Country	Effect
Indonesia	55.62840
Vietnam	36.50404
Thailand	-41.69754
Malaysia	-50.43489

Source: Data processed, 2024

The R square value acquired is 0.9534, indicating that 95.34 percent of the variance in the emissions variable can be elucidated by the GDP variables of the Manufacturing and Renewable Energy sector, with the residual portion being accounted for by other factors. The overall explanation of this model suggests that the Manufacturing GDP variable is associated with a regression coefficient of 2.227, signifying a positive impact of manufacturing production, as represented by GDP, on the emissions of carbon gases.

An increase of 1 billion USD in GDP within the manufacturing domain is anticipated to result in a 2.227 megaton rise in CO_2 emissions, assuming the constancy of other factors. Furthermore, the Renewable Energy variable displays a regression coefficient of -2.291, indicating that a higher utilization of renewable energy sources leads to a reduction in carbon dioxide emissions.

Specifically, a 1 percent escalation in the portion of renewable energy in total energy consumption is expected to lower CO_2 emissions by 2.291 megatons, provided other variables remain unchanged. The random effect value from cross-section analysis reveals that Indonesia exhibits the highest level of CO_2 emissions, followed by Vietnam and Thailand, whereas Malaysia records the least carbon emissions among the four countries, given that the Manufacturing GDP and Renewable Energy variables hold equivalent values across all nations.

The outcomes of this study reveal that Gross Domestic Product (GDP) within the manufacturing industry exerts a positive and notable impact on carbon emissions in Indonesia, Malaysia, Thailand, and Vietnam. This discovery aligns with several prior researches asserting that activities in the manufacturing sector significantly contribute to the rise in carbon emissions.

Saidi and Hammami (2015) as well as Lee and Brahmasrene (2018) observed that the escalation in industrial production tends to elevate carbon emissions due to the substantial consumption of energy and raw materials generated by this sector. Furthermore, Al-Mulali et al. (2015) affirmed through their study that the rapid advancement of the manufacturing industry in developing nations leads to heightened carbon emissions owing to the continued reliance on inefficient technology and high usage of fossil fuels.

On the contrary, the utilization of renewable energy demonstrates an adverse and substantial impact on carbon emissions. This pattern is in line with various investigations by Apergis and Payne (2014) illustrating that a surge in renewable energy adoption contributes to a decline in carbon emissions within OECD countries.

Despite the focus of these studies being on developed nations, similar results were mirrored in developing countries, including those within ASEAN. As evidenced in research by Rahman and Velayutham (2020), the integration of renewable energy showcased a remarkable effect in curbing carbon emissions in Southeast Asia.

Particularly within the countries under scrutiny, there has been a recent uptick in the adoption of renewable energy as part of endeavors to diminish reliance on fossil fuels and adhere to international obligations concerning climate change.

For instance, Indonesia and Thailand have enacted diverse policies to promote the utilization of renewable energy, like fiscal incentives and feed-in tariffs for renewable resources. The examination by Alola et al. (2019) underscores the significance of policies that bolster the advancement of renewable energy in mitigating carbon emissions in developing nations.

Furthermore, the outcomes of this research carry crucial implications for policymakers. Given the empirical proof that the manufacturing sector amplifies carbon emissions, ASEAN countries must devise a well-rounded strategy that not solely fosters economic growth but also takes into account environmental repercussions. One viable measure entails enhancing energy efficiency in the manufacturing domain and broadening the deployment of clean technologies.

Conversely, fortifying policies that bolster the expansion of renewable energy will assume a pivotal role. Increased investments in the infrastructure for renewable energy and technological advancements can expedite the shift towards a low-carbon economy. These discoveries substantiate the notion that while the expansion of the manufacturing industry is vital for economic progress, there exists an urgent necessity to amalgamate robust environmental regulations to ensure that this progress is environmentally sustainable.

CONCLUSION

According to this study, carbon emissions are significantly positively impacted by manufacturing GDP in Indonesia, Malaysia, Thailand, and Vietnam, but carbon emissions are significantly impacted negatively by the usage of renewable energy. This demonstrates how rising manufacturing activity raises carbon emissions because it often relies on fossil fuels.

On the other hand, using renewable energy contributes to a decrease in carbon emissions, emphasizing the significance of switching to clean energy sources. These results highlight the necessity for ASEAN countries to adopt balanced development strategies that promote economic growth while lowering environmental consequences through clean technology, energy efficiency, and renewable energy initiatives.

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