International Journal of Innovative Research and Scientific Studies, 8(4) 2025, pages: 1044-1056

IJIRSS
International Journal of Innovative Research & Scientific Studies

ISSN: 2617-6548

URL: www.ijirss.com

Analyzing determinants of CO2 emissions in ASEAN: Evidence from panel regression and threshold model

Huong Tran Thi[1*], Phuong Tran Thi[2]

[1,2]*School of Economics and Management, Hanoi University of Science and Technology, 000084, Hanoi, Vietnam.*

Corresponding author: Huong Tran Thi (*Email: huong.tranthi@hust.edu.vn*)

Abstract

Climate change caused by greenhouse gas emissions, especially CO_2, is one of the most pressing global issues. Southeast Asia is particularly vulnerable to the impacts of climate change, such as sea level rise, extreme weather events, and changes in rainfall patterns. This study investigates the key factors influencing carbon dioxide (CO_2) emissions across the 10 member states of the Association of Southeast Asian Nations (ASEAN). Panel data regression models are utilized to examine the impacts of economic growth, urbanization, industrialization, and other variables on CO_2 emissions. A fixed effects model finds that GDP has a negative relationship with CO_2, while urbanization and industrialization have positive effects. A panel threshold model further reveals GDP's impact on emissions changes at a threshold. Below this level, GDP decreases CO_2; above the threshold, emissions still decline with GDP growth, but at a slower rate. The results suggest that while ASEAN has pursued economic growth, this has not necessarily led to proportional increases in CO_2. However, industrialization and urbanization are critical factors associated with rising emissions. The study recommends policy implications, including sustainable urban planning, industrial waste management, and green investment incentives.

Keywords: ASEAN countries, CO_2 emissions, determinants, panel regression, threshold model.

DOI: 10.53894/ijirss.v8i4.7990
Funding: This study received no specific financial support.
History: Received: 17 April 2025 / **Revised:** 23 May 2025 / **Accepted:** 26 May 2025 / **Published:** 20 June 2025

Competing Interests: The authors declare that they have no competing interests.
Authors' Contributions: All authors contributed equally to the conception and design of the study. All authors have read and agreed to the published version of the manuscript.
Transparency: The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.
Publisher: Innovative Research Publishing

1. Introduction

In recent decades, carbon dioxide (CO_2) concentration in the Earth's atmosphere has steadily risen. According to observational data from the World Meteorological Organization (WMO), the global average CO_2 level has risen by more than 10% in two decades to 420 ppm in 2023, a new record [1]. This increase far exceeds the Earth's natural limit over millions of years. The substantial increase in atmospheric CO_2 levels is considered the primary cause of global warming: the ongoing rise in Earth's average surface temperature. In Southeast Asia, average temperatures have risen 0.14°C to 0.20°C per decade since the 1960s [2]. Countries like Indonesia and Malaysia have experienced more frequent and intense heat waves, droughts, and heavy rainfall [3]. Flood risk during the rainy season has also increased across mainland Southeast Asia, while drought risk is higher in the dry season, threatening agricultural productivity and food security. Tropical diseases like malaria and dengue fever are also expected to spread as temperatures continue to rise. Given the vulnerability and increasing emissions, there is an urgent need for research on the factors of CO_2 emissions in Southeast Asia to support evidence-based policymaking. The primary objective of this research is to examine the determinants of carbon dioxide (CO_2) emissions within the 10 ASEAN countries. The key factors influencing CO_2 emissions in ASEAN countries are economic growth, foreign direct investment, industrial development, urban population growth, and other relevant factors. By achieving a nuanced understanding of these determinants, the research seeks to contribute valuable insights for policymakers, environmental agencies, and stakeholders in developing targeted strategies and policies aimed at mitigating and managing CO_2 emissions within the ASEAN context.

2. Literature Review

Exploring the determinants of CO_2 emissions has received considerable interest in academia and practice, particularly in the context of emerging economies where rapid development often accompanies environmental degradation. Numerous studies have examined the interrelationship between economic activity and carbon emissions in Southeast Asia, a region characterized by robust economic growth and increasing energy demand. Raihan [4] analyzed time series data of Vietnam from 1984 to 2020, then indicated that energy use and economic growth caused environmental degradation by increasing CO_2 emissions. Thi Quy et al. [5] found a bidirectional relationship between CO_2 emissions and macroeconomic variables such as industrialization, financial development, trade openness, and technological innovation. Sahputra et al. [6] used panel data from 2001 to 2022 of ASEAN-5 countries (Indonesia, Malaysia, the Philippines, Singapore, and Thailand) to demonstrate that non-renewable energy consumption has a positive effect on CO_2 emissions, and this relationship is moderated by economic growth. While the majority of previous research ignored the nonlinear characteristics of the relationship, several studies have used the threshold model to examine the impact of macroeconomic factors on CO_2 emissions in developing countries [7-10]. To our best understanding, there are three major research gaps in the literature. First, most prior research has focused on individual countries or a small subset of ASEAN members, limiting the generalizability of their conclusions. Second, many analyses rely on data that only extend to 2016 or 2018, overlooking recent regional policy shifts and energy trends. Third, despite growing evidence of non-linearities in the growth-emissions relationship, relatively few studies have adopted advanced econometric techniques, such as threshold regression, to explore potential structural changes or conditional effects.

This study aims to address these gaps by employing panel regression and threshold models using updated data (1990–2020, excluding the COVID-19 period) across all ten ASEAN countries: Brunei, Cambodia, Indonesia, Laos, Malaysia, Myanmar, the Philippines, Singapore, Thailand, and Vietnam. By incorporating theoretically and empirically grounded variables economic growth, energy consumption, trade openness, industrialization, urbanization, and deforestation the study seeks to capture the multifaceted nature of emissions dynamics. It contributes to the academic literature and policymaking by identifying emission drivers and potential thresholds that can inform more targeted and effective mitigation strategies across Southeast Asia.

3. Methodology

3.1. Research Model and Hypotheses

Based on the previous research document, this study will estimate panel regression models to examine the impact of economic growth, foreign direct investment (FDI), urbanization, and industrialization on CO_2 emissions in ASEAN countries from 2000 to 2020. We propose the following hypotheses:

H_1: An increase in GDP is associated with a proportional increase in CO_2 emissions.

H_2: Increased FDI is positively correlated with higher CO_2 emissions.

H_3: Urbanization is positively linked to the increase in CO_2 emissions.

H_4: Industrialization leads to a significant increase in CO_2.

H_5: An inverted U-shaped relationship exists between GDP and CO_2 emissions, wherein emissions increase to a threshold GDP level and decrease thereafter.

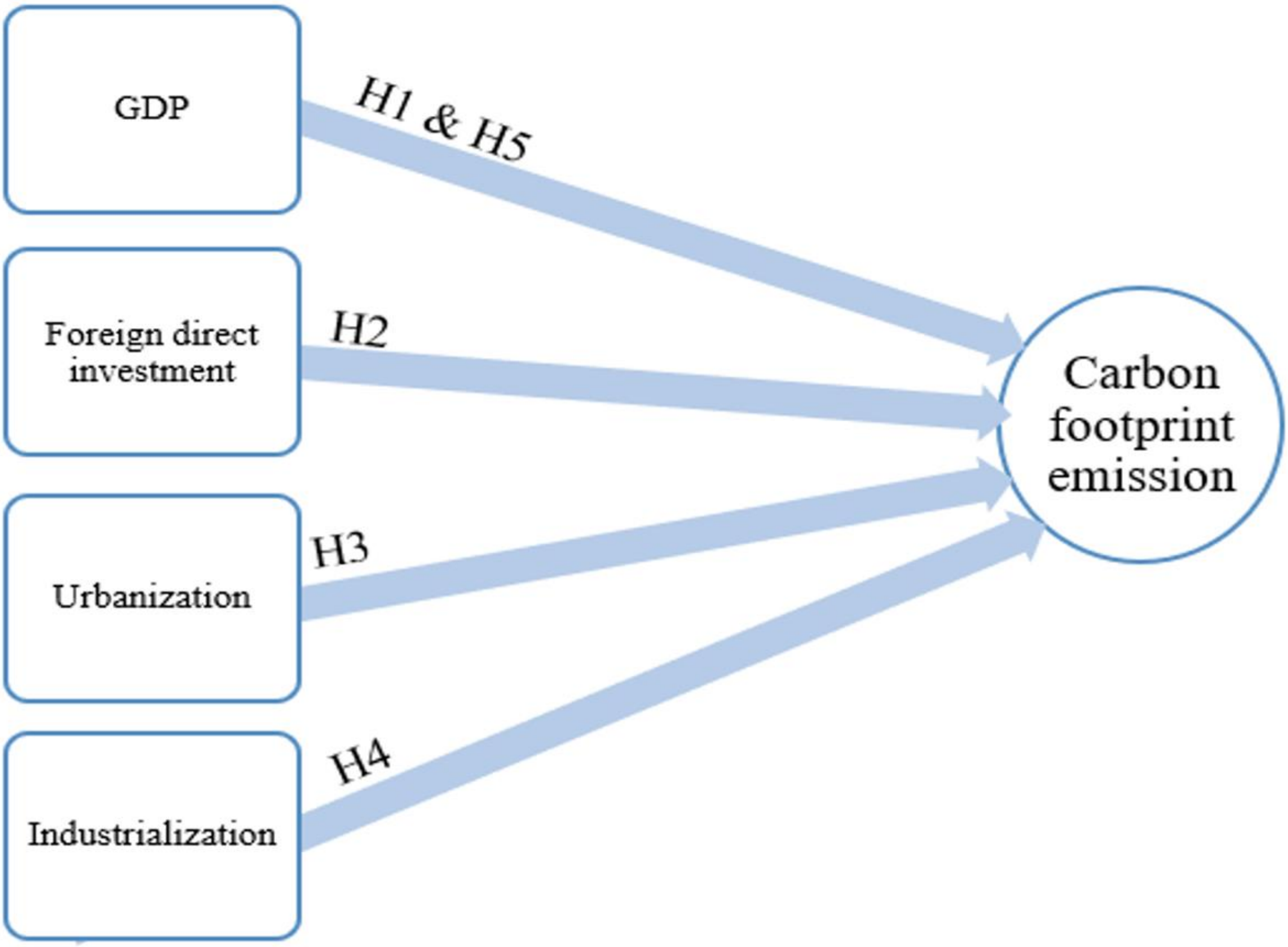

Figure 1.
Research model and hypotheses.
Note: This figure was prepared by the authors.

3.2. Data Collection

The study uses panel data covering 2000–2020 on 10 ASEAN countries: Brunei, Cambodia, Indonesia, Laos, Malaysia, Myanmar, the Philippines, Thailand, Vietnam, and Singapore. These countries were selected based on data availability on all the variables of interest. Table 2 presents the variables used. CO_2 emissions are the total amount of carbon dioxide (CO_2) released into the atmosphere, measured in kilotons. Economic growth is measured as Gross Domestic Product (GDP) and Foreign Direct Investment (FDI). Gross Domestic Product is measured in current United States dollars, and FDI measures the lasting foreign investment entering a country, reflecting the difference between inflows and outflows recorded in the balance of payments, expressed in current US dollars. Urbanization is measured as the total number of people living in urban areas. Industrialization is measured as "Industry (including construction), value added (current US$)," which represents the net output of sectors including manufacturing, construction, and related divisions (ISIC 05-43), measured in current US dollars. It encompasses the total value created by these sectors, excluding deductions for asset depreciation or depletion of natural resources. Additionally, we introduce a time trend variable to capture potential time-related trends in the data. All data were sourced from the World Bank Development Indicators. All were transformed to the natural log or differentiated before being used for analysis.

Table 1.
Variables Description.

Variable name	**Symbol**	**Measurement**
CO_2 emissions	lg_co$_2$e	CO_2 emissions kt
Gross domestic product	lg_gdp	GDP (current US$)
Foreign Direct Investment	lg_fdi	Foreign direct investment, net inflows (BoP, current US$)
Urbanization	lg_urbpop	People living in urban areas
Industrialization	lg_idus	Industry (including construction), value added (current US$)
Time trend	t	

3.3. Data Analysis

In this research, we used Panel Regression Analysis and Panel Threshold Analysis.

3.3.1. Panel Regression Analysis

There are three models to examine the impact of economic growth, foreign direct investment (FDI), urbanization, and industrialization on CO_2 emissions.

- Pooled Ordinary Least Squares Model: The Pooled OLS model combines all panel data into a single dataset, ignoring the panel structure (without distinguishing between entities or time). This model estimates parameters using the ordinary least squares (OLS) method.
- Fixed Effects Model: The Fixed Effects model accounts for individual-specific effects that may be constant over time. This is particularly useful when dealing with unobserved heterogeneity across entities in a panel dataset.
- Random Effects Model: This model assumes that the individual-specific effects of entities are random, uncorrelated with the independent variables, and have a specific variance.

When conducting panel data regression, a key decision is choosing among a fixed effects model (FEM), a pooled ordinary least squares (POLS) model, and a random effects model (REM). There are two common tests used to guide this choice: the Lagrange multiplier (LM) test for random effects and the Hausman test comparing fixed versus random effects. The LM test can be used to evaluate whether a random effects model is preferred over a simple OLS pooled regression model, while the Hausman test can be used to test whether FEM or REM is more appropriate.

In this research, we will use both tests to choose the appropriate model for Panel Regression Analysis.

We first preprocess the collected data and manage missing values using Microsoft Excel. Further analysis was then conducted using two powerful statistical software tools: EViews 12 and Stata/MP version 17.0.

3.3.2. Panel Threshold Analysis

The panel threshold regression (PTR) model is an increasingly popular approach in econometrics that allows for estimating nonlinear relationships with threshold effects in panel data settings. The PTR model was proposed by Hansen [11] and extends standard panel data methods by incorporating one or more threshold variables that determine different regression regimes. The general formulation of the PTR model with a single threshold is:

$$y_{it} = \mu_i + \beta_1' x_{it} + \varepsilon_{it} \text{ if } q_{it} <= \gamma$$
$$y_{it} = \mu_i + \beta_2' x_{it} + \varepsilon_{it} \text{ if } q_{it} > \gamma$$

Where *i* denotes cross-sectional units, *t* denotes time periods, qit is the threshold variable, γ is the estimated threshold value, μ_i are fixed effects, x_{it} are covariates, and ε_{it} is the error term. The threshold variable q_{it} divides the observations into different regimes based on whether it is above or below the threshold γ. The coefficients β_1 and β_2 are allowed to differ across regimes, capturing differential effects of the covariates x_{it}.

Key features of the PTR model include (i) allowing estimation of nonlinear and discontinuous relationships, (ii) being useful for modeling structural breaks or policy regime shifts, and (iii) supporting the identification of tipping points or critical thresholds.

The model has been widely applied in recent economic research to identify tipping points and structural breaks in areas such as environmental Kuznets curves, growth convergence, inflation targeting, and fiscal sustainability. This study will adopt the fixed-effect PTR approach to examine the relationship between economic growth and CO_2 emissions.

4. Results

4.1. Descriptive Statistics

To gain insights into the characteristics of the dataset, the visualization for the variables under analysis is presented in Figures 2 to 6.

Figure 2 shows CO_2 emissions from 2000 to 2020 for 10 ASEAN countries: Brunei, Indonesia, Cambodia, Laos, Myanmar, Malaysia, Philippines, Singapore, Thailand, and Vietnam. Overall, emissions grew substantially over the period for most countries, though Singapore and Brunei saw more stable or declining trajectories. Indonesia stands out as the largest emitter by far, with over 500,000 kt of CO_2 in 2020 and increases exceeding 200,000 kt from 2000. Other major emitters include Thailand, Malaysia, the Philippines, and Vietnam, all with over 100,000 kt by 2020. Emissions grew rapidly in Vietnam and the Philippines, rising over 200% and 85% respectively from 2000 to 2020. Meanwhile, Singapore managed to modestly reduce emissions from around 42,000 kt to 44,000 kt over the period. Laos and Myanmar saw dramatic percentage increases in emissions, but from smaller bases of around 1,000 kt in 2000. Continued efforts will be needed to curb emissions growth while maintaining economic progress across these diverse ASEAN nations.

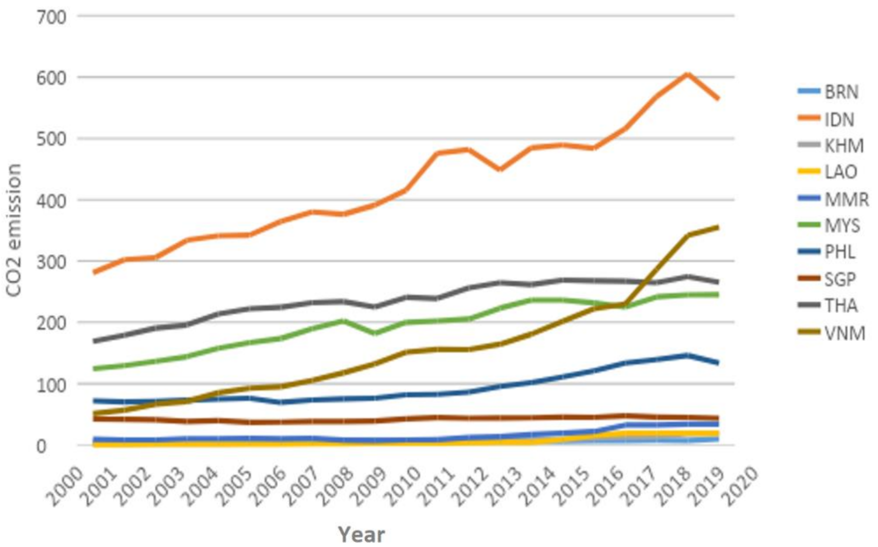

Figure 2.
CO2 emissions in ASEAN from 2000 to 2020.

Figure 3 shows substantial urbanization occurring across the ASEAN region over the past two decades. Indonesia stands out with the largest urban population by far, growing from around 90 million in 2000 to over 150 million by 2020. Other populous urban countries include the Philippines, Vietnam, Thailand, and Malaysia, each with over 25 million urban dwellers by 2020. Meanwhile, Singapore and Brunei maintained relatively stable urban populations of around 5 million and 350,000, respectively, over the period. In percentage terms, Laos, Cambodia, and Myanmar saw the most dramatic urbanization, approximately doubling their urban populations, though from smaller initial bases.

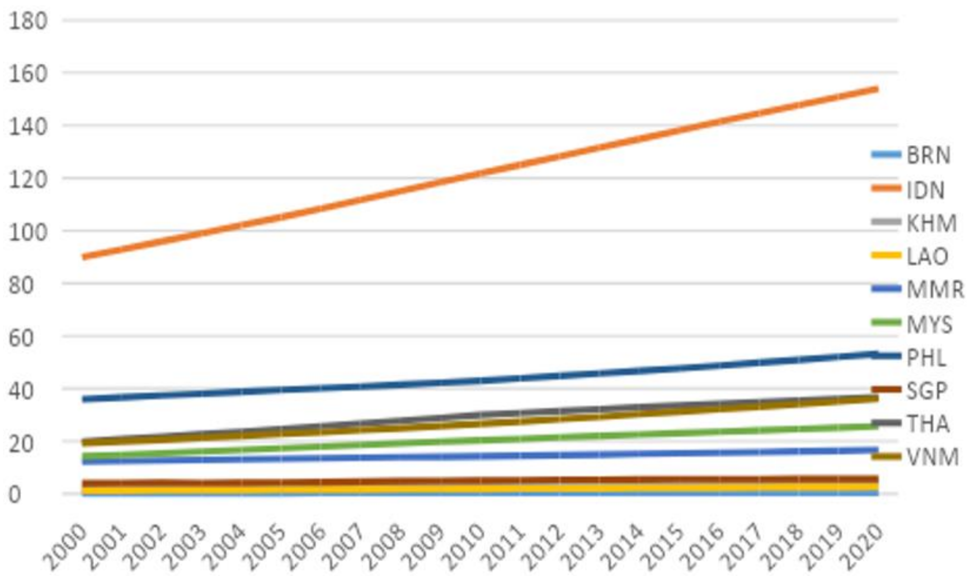

Figure 3.
Urban Population in 10 ASEAN countries from 2000 to 2020.
Note: This figure was prepared by the authors.

Following rapid urbanization across the region, the ASEAN countries also experienced substantial economic growth from 2000-2020, as reflected in the GDP data showing divergence across countries (see Figure 4.). Indonesia maintained its position as the largest economy in the region throughout the period, with GDP exceeding $1 trillion by 2020. Other major economies include Thailand, Malaysia, the Philippines, and Singapore, all of which saw GDP grow to over $300 billion by 2020. Vietnam posted the fastest growth rates, with GDP multiplying by around 11 times from 2000 to 2020. Meanwhile, Brunei experienced volatile GDP fluctuations due to oil prices, given its resource dependence.

In percentage terms, Cambodia, Laos, and Myanmar grew rapidly off smaller bases, with GDP multiplying 4-5 times over the period. The data reflect the robust economic expansion of ASEAN, with the region becoming an engine of growth in Asia. However, development gaps remain between slower-growing countries like Myanmar and faster-expanding economies such as Vietnam and the Philippines. Overall, ASEAN's GDP increased from around $2.5 trillion in 2000 to over $10 trillion by 2020, demonstrating its emergence as a key part of the global economy.

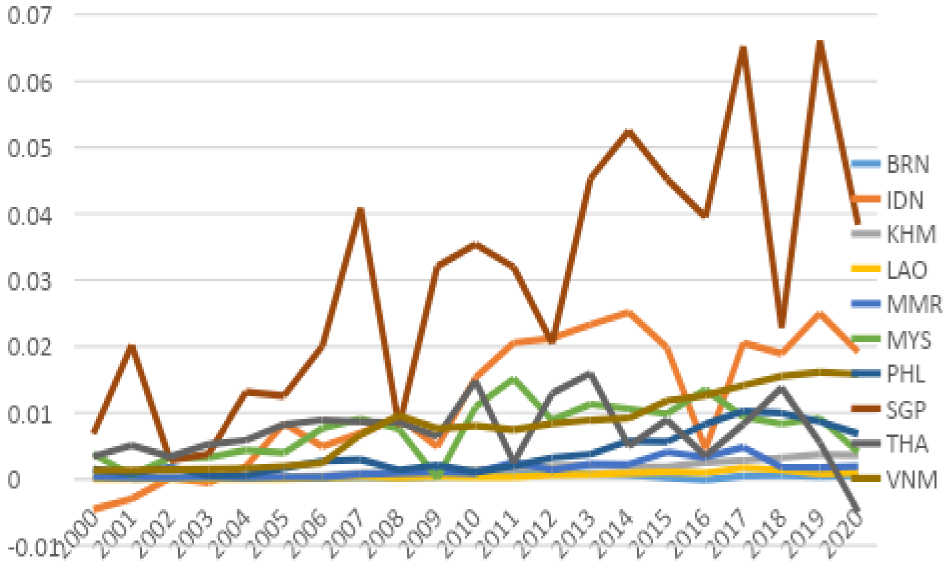

Figure 4.
GDP in 10 ASEAN countries from 2000 to 2020.

Building on the previous trends in urbanization and economic growth, industrial value added also expanded substantially across the ASEAN region between 2000 and 2020 (see Figure 5). Indonesia again led in total industrial output, with its value added exceeding $4 trillion by 2020. Major industrial producers include Thailand, Malaysia, the Philippines, and Vietnam, all of which saw industry value added rise to over $1 trillion by 2020. Singapore's industrial output remained relatively stable at around $800-900 billion despite its lack of population and geographic scale. Myanmar, Cambodia, and Laos grew rapidly from low bases, though they still constitute a small share of ASEAN industrial activity. Overall, the data reflect ASEAN's growing strength as a manufacturing hub and its increasing industrial capacity.

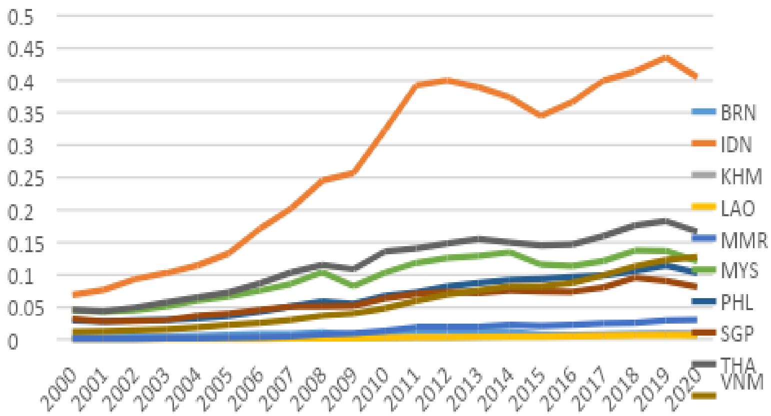

Figure 5.
Industrial value in 10 ASEAN countries from 2000 to 2020.

Foreign direct investment (FDI) into ASEAN also increased substantially from 2000 to 2020, albeit with high year-on-year volatility. Singapore led in attracting FDI among ASEAN nations, with inflows exceeding $65 billion by 2019. Indonesia, Vietnam, Malaysia, and Thailand also saw sizable FDI totaling over $20 billion in the latter years. However, flows were highly unstable, fluctuating widely during economic cycles and crises. For instance, Indonesia experienced net FDI outflows during the Asian Financial Crisis in the early 2000s before rising rapidly in the 2010s. Meanwhile, poorer nations like Laos and Cambodia grew FDI inflows steadily but from small bases under $1 billion in 2000. On average, ASEAN FDI rose from around $90 billion in 2000 to exceed $160 billion by 2020. However, the volatility highlights the region's exposure to global capital flows and investment shifts. Managing FDI stability amidst changing market conditions remains an important policy priority to maintain ASEAN's growth momentum.

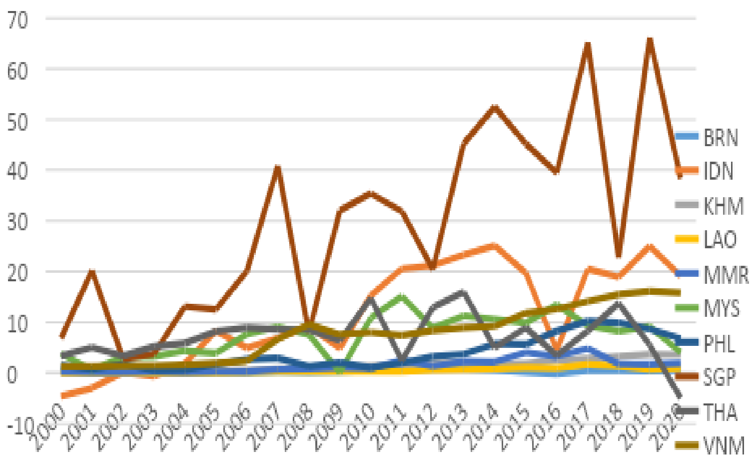

Figure 6.
FDI in ASEAN from 2000 to 2020.

4.2. Testing the Fixed Effects to Select the Appropriate Regression Model

In this section, we present the results of the Hausman test and the LM test to examine fixed effects to determine the most appropriate model.

4.2.1. The Lagrange Multiplier Test

The LM test results (Table 2) include the Breusch-Pagan, Honda, King-Wu, and standardized versions, all of which reject the null hypothesis at the 1% significance level based on the p-values less than 0.01. This provides strong evidence against the null hypothesis, suggesting that a random effects model is statistically preferred.

Table 2.
Lagrange Multiplier Tests for Random Effects.

Null hypotheses: No effects			
Alternative hypotheses: Two-sided (Breusch-Pagan) and one-sided (all others) alternatives			
Test Hypothesis			
	Cross-section	**Time**	**Both**
Breusch-Pagan	247.9866	6.609791	254.5964
	0.000	-0.0101	0.000
Honda	15.74759	2.570951	12.95317
	0.000	-0.0051	0.000
King-Wu	15.74759	2.570951	14.5122
	0.000	-0.0051	0.000
Standardized Honda	21.32969	2.897541	11.3033
	0.000	-0.0019	0.000
Standardized King-Wu	21.32969	2.897541	14.07239
	0.000	-0.0019	0.000

4.3. The Hausman Test

The Hausman test statistic of 80.55286 with 5 degrees of freedom is highly significant, with a p-value less than 0.01. This provides strong evidence to reject the null hypothesis. Therefore, we can conclude that the fixed effects model is statistically preferred over the random effects model for this panel data based on the Hausman test results.

Table 3.
Correlated Random Effects - Hausman Test.

Equation: Untitled			
Test cross-section random effects			
Test Summary	**Chi-Sq. Statistic**	**Chi-Sq. d.f.**	**Prob.**
Cross-section random	80.55286	5.000	0.000

Based on the outcomes of the Lagrange Multiplier tests, it is evident that the REM demonstrates a superior fit in comparison to the POLS model. When comparing the FEM and the REM, the Hausman test shows that FEM exhibits a suitable choice. Therefore, in this study, FEM is selected for model implementation.

Table 4.
Cross-section dependence test.

Test	Breusch-Pagan LM	Pesaran scaled LM	Bias-corrected scaled LM	Pesaran CD
CO2E	600.72	58.58	58.33	23.99
	(0.000)	(0.000)	(0.000)	(0.000)
GDP	803.51	79.95	79.70	28.07
	(0.000)	(0.000)	(0.000)	(0.000)
IDUS	732.17	72.43	72.18	26.46
	(0.000)	(0.000)	(0.000)	(0.000)
URBPOP	925.61	92.82	92.57	30.42
	(0.000)	(0.000)	(0.000)	(0.000)
FDI	333.55	30.42	30.17	16.03
	(0.000)	(0.000)	(0.000)	(0.000)

4.4. Cross-Section Dependence Test

The results from the cross-section dependence tests provide valuable insights into the relationships between various variables within the panel dataset covering the years 2000 to 2020. The null hypothesis, which assumes no cross-sectional dependence or correlation, is convincingly rejected across all tested variables.

The four cross-section dependence tests—Breusch-Pagan LM, Pesaran scaled LM, bias-corrected scaled LM, and Pesaran CD—all yield consistent results. The null hypothesis of no cross-section dependence is uniformly rejected for the CO_2E, GDP, IDUS, URBPOP, and FDI variables, indicating significant cross-sectional correlation across the examined panel dataset from 2000 to 2020.

4.5. Unit Root Test

The purpose of this section is to employ unit root tests, specifically the PANIC (Panel Analysis of Nonstationarity in Idiosyncratic and Common Components) test, to examine the stationarity of each variable. The unit root tests aim to determine whether the variables exhibit a unit root, indicative of non-stationary behavior [12]. In this context, the PANIC test is particularly valuable as it accounts for cross-sectional dependence, providing robust results in the presence of potential correlation among cross-sectional units. By evaluating the stationarity of each variable, we can make informed decisions about the suitability of the data for panel analysis and refine our understanding of the underlying dynamics of the studied phenomena.

Table 5.
Unit root test.

Variable	CO_2E	GDP	URBPOP	IDUS	FDI
Values	1.6012	6.2256	+infi	1.5570	0.2766
p_value	>=0.10	<0.01	<0.01	>=0.10	>=0.10
Log/1st diff (Value)	2.7454			3.3083	4.1144
p_value	<0.01			<0.01	<0.01
Conclusion	log	log	log	log	diff

Based on the results in Table 5, we can draw the following conclusions:

- CO_2E: This series is stationary at the level, meaning it does not contain a unit root.
- GDP: Similar to CO_2E, the GDP series is non-stationary at the level but becomes stationary after taking the logarithm.
- URBPOP: This series is stationary at the level, meaning it does not contain a unit root.
- IDUS: This series is non-stationary at the level but becomes stationary after taking the logarithm.
- FDI: This series is non-stationary at the level but becomes stationary after taking the first difference.

In summary, all series are non-stationary at the level but become stationary after they are transformed, either by taking the logarithm or the first difference.

4.6. Fix Effect Regression Model

The panel least squares regression with fixed effects was estimated using annual data from 2000 to 2020 across 10 cross-sections for a total of 205 observations. The dependent variable is the natural logarithm of CO_2 emissions (LG_CO_2E). The independent variables are the natural logarithms of GDP (LG_GDP) and urban population (LG_URB), the square of foreign direct investment (LG2_FDI), the natural logarithm of industrialization (LG_IDUS), and a time trend.

Based on the result of the first model in Table 6, the author decides to exclude the variable representing foreign direct investment (FDI) from the model because of the statistical insignificance of FDI in the fixed-effects regression analysis. The coefficient for the FDI variable (d_fdi) is reported to be 1.19E-12 with a standard error of 2.43E-12, yielding a t-statistic of 0.49 and a p-value of 0.625. This p-value exceeds the conventional threshold for statistical significance, indicating that FDI does not have a statistically significant impact on CO_2 emissions within the context of this model.

lg_gdp, lg_idus, lg_urb, and time (t) all have significant coefficients with very low p-values, suggesting strong and statistically significant relationships with CO_2 emissions.

Furthermore, simplifying the model by excluding non-significant variables can prevent overfitting, where a model may describe random error or noise rather than the underlying relationship. It also reduces the risk of multicollinearity, which can occur when independent variables are highly correlated with each other.

The results in Table 7 show that GDP, urbanization, industrialization, and the time trend are statistically significant predictors of CO_2 emissions at the 5% level. Specifically, a 1% increase in average GDP is associated with a 0.87% decrease in average CO_2 emissions, holding other factors constant. A 1% increase in average urban population and industrialization is estimated to increase the average CO_2 emissions by 3.67% and 0.87%, respectively. The time trend indicates that the mean CO_2 emissions are decreasing by about 0.038% per year over the sample period.

The model has a high R-squared of 0.75, indicating it explains approximately 75% of the variation in CO_2 emissions. The F-statistic is significant at the 1% level, rejecting the null hypothesis that all coefficients are jointly zero. Additionally, the model accounts for unobserved time-invariant country-specific factors through fixed effects. The residuals are not correlated across countries or with the independent variables. Based on these results, GDP, urbanization, industrialization, and time trends are important determinants of CO_2 emissions.

Table 6.
First model estimation.

Fixed-effects (within) regression	Number of obs. = 200				
Group variable: id	Number of groups = 10				
R-squared:	Obs. per group:				
Within = 0.7548	min. = 20				
Between = 0.7388	avg = 20.0				
Overall = 0.7031	max. = 20				
F (5,185) = 113.88					
corr(u_i, Xb) = -0.9858	Prob > F = 0.0000				
lg_co2e	**Coefficient**	**Std. Err.**	**t**	**P>|t|**	**[95% conf. interval]**
lg_gdp	-1.160175	0.20971	-5.53	0	-1.573905 -0.7464447
lg_idus	1.070886	0.140892	7.6	0	0.7929238 1.348849
lg_urb	4.115431	0.472461	8.71	0	3.183327 5.047535
d_fdi	1.19E-12	2.43E-12	0.49	0.625	-3.60e-12 5.98e-12
t	-0.0384472	0.011685	-3.29	0.001	-0.0614994 -0.0153949
_cons	-51.85962	6.73538	-7.7	0	-65.14765 -38.57159
sigma_u | 5.7030128					
sigma_e | .24974101					
rho | .99808601 (fraction of variance due to u_i)					
F test that all u_i=0: F(9, 185) = 40.70 Prob > F = 0.0000					

Table 7.
Fixed-effect model estimation.

Fixed-effects (within) regression	Number of obs. = 210				
Group variable: id	Number of groups = 10				
R-squared:	Obs per group:				
Within = 0.7489	min. = 21				
Between = 0.7434	avg = 21.0				
Overall = 0.7082	max. = 21				
F(4,196)	= 146.14				
corr(u_i, Xb) = -0.9819	Prob > F = 0.0000				
lg_co2e	**Coefficient**	**Std. err.**	**t**	**P>|t|**	**[95% conf. interval]**
lg_gdp	-0.8742689	0.3379001	-2.59	0.029	-1.638652 -.1098858
lg_idus	0.8765737	0.2633895	3.33	0.009	.2807453 1.472402
lg_urb	3.673258	0.4947893	7.42	0.000	2.553967 4.792549
t	-0.0385672	0.0104352	-3.7	0.005	-.0621732 -.0149611
_cons	-47.22089	6.587528	-7.17	0.000	-62.12291 -32.31886
sigma_u | 5.0456972					
sigma_e | .25744167					
rho | .99740351 (fraction of variance due to u_i)					
F test that all u_i=0: F(9, 196) = 38.54	Prob > F = 0.0000				

4.7. Economic Growth Threshold with Carbon Footprint Emission

The results of the fixed-effects panel threshold regression model in Table 8 reveal several key insights into the relationship between CO_2 emissions and GDP, as well as other factors. The model was run on a dataset of 210 observations, grouped into 10 categories. The R-squared values indicate a strong fit for the model, with the within-group R-squared at 0.7889, between-group at 0.7512, and overall at 0.7204.

The threshold estimator, at a 95% confidence level, was found to be 22.6369, with a lower limit of 22.6039 and an upper limit of 22.7901. This threshold value is crucial in understanding the relationship between CO_2 emissions and GDP.

The coefficient of lg_gdp is -0.65749, indicating a negative relationship between GDP and CO_2 emissions. This suggests that as GDP increases, CO_2 emissions decrease, holding all other variables constant. However, this relationship changes when the threshold is crossed.

The interaction term _cat#c.lg_co2e has a coefficient of 0.0559553. This indicates that when the threshold is crossed (i.e., _cat changes from 0 to 1), the relationship between CO_2 emissions and GDP changes. In other words, beyond this threshold, an increase in GDP is still associated with a decrease in CO_2 emissions, but at a slower rate than below the threshold.

Other variables in the model, such as industrialization and urbanization, also show significant relationships with CO_2 emissions. The positive coefficients suggest that increases in these variables are associated with increases in CO_2 emissions.

The results suggest a complex relationship between CO_2 emissions and GDP, which changes depending on whether a certain threshold is crossed. This could have important implications for environmental and economic policy, as it suggests that efforts to increase GDP could lead to increased CO_2 emissions beyond a certain point.

Table 8.
Economic growth threshold with Carbon footprint emission.

Model	Threshold	Lower	Upper		
Th-1	22.6369	22.6039	22.7901		
Fixed-effects (within) regression		Number of obs = 210			
Group variable: id		Number of groups = 10			
R-sq: Within = 0.7889		Obs per group: min = 21			
Between = 0.7512		avg = 21.0			
Overall = 0.7204		max = 21			
F(5,195) = 145.76					
corr(u_i, Xb) = -0.9744		Prob > F = 0.0000			
lg_co2e	Coefficient	Std. err.	t	P>|t|	[95% conf. interval]
lg_gdp	-0.65749	0.185017	-3.55	0	-1.022382 -0.2925984
lg_idus	0.648463	0.125067	5.18	0	0.4018055 0.8951195
lg_urb	3.106887	0.408735	7.6	0	2.300778 3.912997
t	-0.033058	0.0103	-3.21	0.002	-0.0533717 -0.012744
_cat#c.lg_co2e					
0	0				
1	0.055955	0.009202	6.08	0	0.0378064 0.0741042
_cons	-38.67276	5.863398	-6.6	0	-50.23657 -27.10894
sigma_u | 4.1752885					
sigma_e | .23663987					
rho | .99679808 (fraction of variance due to u_i)					
F test that all u_i=0: F(9, 195) = 42.87		Prob > F = 0.0000			

5. Discussion and Implications

Based on the analysis of the fixed-effects and panel threshold regression model, the following conclusions can be drawn regarding the hypotheses:

Hypothesis 1: An increase in GDP is associated with a proportional increase in CO_2 emissions. This hypothesis is rejected. The coefficient of lg_gdp is -0.65749, indicating a negative relationship between GDP and CO_2 emissions. This suggests that as GDP increases, CO2 emissions decrease, holding all other variables constant. Therefore, economic growth in ASEAN countries may be achieved in a manner that is increasingly less carbon-intensive. To further enhance this trend, the following solutions could be considered:

- Promoting green technologies: Encouraging the development and use of technologies that are environmentally friendly and energy-efficient can help reduce CO_2 emissions while maintaining economic growth. For instance, ASEAN countries could invest in research and development of renewable energy technologies, such as solar and wind power, and provide incentives for businesses to adopt these technologies.
- Implementing carbon pricing mechanisms: Introducing policies such as carbon taxes or cap-and-trade systems can provide economic incentives for businesses to reduce their carbon emissions. This can be achieved by setting a price on carbon emissions, which would encourage businesses to reduce their emissions in order to save costs. ASEAN countries could also consider regional cooperation in implementing such mechanisms to ensure effectiveness and avoid competitiveness issues.
- Encouraging sustainable practices in businesses: Policies and initiatives that promote sustainable business practices, such as energy efficiency and waste reduction, can contribute to lower CO_2 emissions. This could include providing training and resources for businesses to implement sustainable practices, as well as recognizing and rewarding businesses that demonstrate leadership in sustainability.

Hypothesis 2: Hypothesis 2, which suggested that increased FDI is positively correlated with higher CO_2 emissions, was not tested in the model due to the statistical insignificance of the FDI variable. This could be due to a variety of factors, such as the nature of the investments being made or the policies in place in the countries receiving the investments. For instance, if FDI is primarily going into sectors that are not carbon-intensive, or if the receiving countries have strong environmental regulations in place, the impact of FDI on CO_2 emissions could be minimal. To ensure that FDI does not lead to increased CO_2 emissions, policy recommendations could include:

- Strengthening environmental regulations: Governments could implement or strengthen regulations that require businesses to limit their CO_2 emissions, which would apply to both domestic businesses and foreign investors.
- Promoting green investments: Governments could provide incentives for foreign investors to invest in green technologies or industries, which could help to reduce CO_2 emissions.

- Implementing transparency measures: By requiring businesses to disclose their CO_2 emissions, governments can make it easier for investors to take these factors into account when making investment decisions.

Hypothesis 3: Urbanization is positively linked to the increase in CO_2 emissions. This hypothesis is accepted. The coefficient of lg_urb is 3.106887, indicating a positive relationship between urbanization and CO_2 emissions. This suggests that as urbanization increases, CO_2 emissions also increase. To manage this, the following solutions could be considered:

- Promoting sustainable urban planning: Implementing urban planning strategies that promote efficient use of resources can help manage the environmental impact of urbanization. This means we need to design and manage cities to consider social, economic, and environmental factors, to improve the quality of life for current and future generations, and to improve the quality of life for current and future generations. While minimizing the negative impacts of urbanization on natural resources and ecosystems.
- Encouraging the use of public transport: Policies that promote the use of public transport can help reduce carbon emissions associated with private vehicle use in urban areas. This means we need to create mechanisms to encourage travel by public transportation, such as buses, subways, and bicycles, instead of using personal vehicles.
- Implementing green construction standards: Encouraging the construction of energy-efficient buildings can help reduce carbon emissions associated with the urban built environment. This can be achieved through the creation of building regulations and standards that promote the construction of energy-efficient buildings, the use of renewable energy sources, and the minimization of environmental impact.

Hypothesis 4: Industrialization leads to a significant increase in CO_2. This hypothesis is accepted. The coefficient of lg_idus is 0.6484625, indicating a positive relationship between industrialization and CO_2 emissions. This suggests that as industrialization increases, CO_2 emissions also increase. To manage this, the following solutions could be considered:

- Advocating for cleaner production technologies: The integration of cleaner and more energy-efficient production technologies can aid in diminishing the carbon emissions associated with industrial operations. This could involve the development of policies and regulations that incentivize the adoption of cleaner production technologies, such as resource conservation, elimination of toxic materials, and optimization of production processes to minimize environmental harm.
- Implementing industrial waste management strategies: Policies that foster efficient management and reduction of industrial waste can contribute to mitigating the environmental impact of industrialization. This could encompass the establishment of waste management standards and regulations, such as waste recycling, waste reduction, and the use of advanced technologies for safe and efficient waste treatment.
- Endorsing the circular economy: Policies that support the circular economy, including recycling and resource recovery, can assist in reducing the carbon emissions associated with industrial operations. This could involve the creation of policies and regulations that promote the reuse and recycling of materials, as well as the exploration and application of innovative solutions for efficient resource recovery and reuse.

Hypothesis 5: There exists an inverted U-shaped relationship between GDP and CO_2 emissions, wherein emissions increase up to a threshold GDP level and decrease thereafter. This hypothesis is partially accepted. The threshold estimator is 22.6369, indicating that there is indeed a threshold GDP level at which the relationship between GDP and CO_2 emissions changes. However, the relationship is not exactly as hypothesized. Below the threshold, an increase in GDP is associated with a decrease in CO_2 emissions. Above the threshold, an increase in GDP is still associated with a decrease in CO_2 emissions, but at a slower rate. This suggests that efforts to increase GDP could lead to increased CO_2 emissions beyond a certain point. To manage this, the following solutions could be considered:

- § Implementing sustainable growth strategies: The introduction of policies that foster sustainable economic growth, such as green growth strategies, can aid in managing the environmental impact of economic development. This could involve the development of strategies that balance economic growth with environmental sustainability, such as the use of renewable energy, the promotion of green jobs, and the implementation of practices that reduce environmental degradation and preserve natural resources.
- Encouraging sustainable consumption: The promotion of policies that foster sustainable consumption behaviors can aid in reducing the demand for carbon-intensive goods and services. This could involve the development of policies and regulations that encourage consumers to make environmentally friendly choices, such as buying products that are made from recycled materials, reducing waste, and choosing services that have a lower carbon footprint.
- Promoting green investment: The encouragement of investment in green industries and technologies can stimulate economic growth while reducing carbon emissions. This could involve the development of financial incentives for businesses that invest in green technologies, the promotion of research and development in green industries, and the implementation of regulations that encourage the transition to a green economy.

6. Conclusion

This study makes several key contributions to the literature on CO_2 emissions and their socioeconomic drivers in Southeast Asia. Firstly, it provides updated empirical evidence on emissions determinants using recent data from 2000 to 2020 across all 10 ASEAN member states. Much prior research has focused on individual countries or smaller country groups within ASEAN. By encompassing the entire region, this study allows for valuable cross-country comparisons. Secondly, the use of panel data methods accounts for unobserved heterogeneity across countries through fixed effects estimation. This helps isolate the impacts of time-varying factors like GDP, urbanization, and industrialization. Thirdly, the panel threshold model provides unique insights into structural breaks and nonlinearity in the relationship between economic growth and emissions.

The estimated GDP turning point for CO_2 emissions has important implications for sustainable development policies.

One of our limitations is the time range of data. The objective is to avoid the effect of COVID-19 on the model variables. Future research can investigate how to utilize updated data. In addition, in our study, we only examined one threshold, not multiple thresholds, for each variable. Furthermore, researchers can make comparisons between different regions of developing or emerging economies to gain more insights into the research topic. Finally, in the digital era, it is necessary to explore the impact of factors related to digital economies on CO_2 emissions.

References

[1] WCO, "Greenhouse gas concentrations surge again to new record in world meteorological organization," Retrieved: https://public.wmo.int/news/media-centre/greenhouse-gas-concentrations-surge-again-new-record-2023, 2023.

[2] D. A. Raitzer, F. Bosello, M. Tavoni, C. Orecchia, G. Marangoni, and J. N. G. Samson, *Southeast Asia and the economics of global climate stabilization*. Asian Development Bank, 2015.

[3] X. X. Li, C. Yuan, and J. Hang, "Heat wave trends in Southeast Asia: Comparison of results from observation and reanalysis data," *Geophysical Research Letters,* vol. 49, no. 4, p. e2021GL097151, 2022. https://doi.org/10.1029/2021GL097151

[4] A. Raihan, "An econometric evaluation of the effects of economic growth, energy use, and agricultural value added on carbon dioxide emissions in Vietnam," *Asia-Pacific Journal of Regional Science,* vol. 7, no. 3, pp. 665-696, 2023. https://doi.org/10.1007/s41685-023-00278-7

[5] N. Thi Quy, N. C. Hai, and H. T. T. Dao, "Time-varying causality relationships between trade openness, technological innovation, industrialization, financial development, and carbon emissions in Thailand," *Plos One,* vol. 19, no. 5, p. e0304830, 2024. https://doi.org/10.1371/journal.pone.0304830

[6] K. Sahputra, S. Syahnur, and V. Silvia, "The role of economic growth in moderating the impact of energy consumption on carbon emissions in ASEAN-5," *Ekonomikalia Journal of Economics,* vol. 3, no. 1, pp. 1-14, 2025. https://doi.org/10.60084/eje.v3i1.242

[7] G. C. Aye and P. E. Edoja, "Effect of economic growth on CO2 emission in developing countries: Evidence from a dynamic panel threshold model," *Cogent Economics & Finance,* vol. 5, no. 1, p. 1379239, 2017. https://doi.org/10.1080/23322039.2017.1379239

[8] C. Chen, M. Pinar, and T. Stengos, "Renewable energy and CO2 emissions: New evidence with the panel threshold model," *Renewable Energy,* vol. 194, pp. 117-128, 2022. https://doi.org/10.1016/j.renene.2022.05.095

[9] M. Liu, M. Zhan, Y. Liu, and M. Zhao, "Impact of FDI and foreign trade openness on carbon emissions in China: evidence from threshold regression model," *Applied Economics,* vol. 56, no. 58, pp. 8332-8345, 2024. https://doi.org/10.1080/00036846.2023.2290589

[10] Q. Wang, J. Sun, U. K. Pata, R. Li, and M. T. Kartal, "Digital economy and carbon dioxide emissions: examining the role of threshold variables," *Geoscience Frontiers,* vol. 15, no. 3, p. 101644, 2024. https://doi.org/10.1016/j.gsf.2023.101644

[11] B. E. Hansen, "Threshold effects in non-dynamic panels: Estimation, testing, and inference," *Journal of econometrics,* vol. 93, no. 2, pp. 345-368, 1999. https://doi.org/10.1016/S0304-4076(99)00025-1

[12] J. Bai and S. Ng, "A PANIC attack on unit roots and cointegration," *Econometrica,* vol. 72, no. 4, pp. 1127-1177, 2004. https://doi.org/10.1111/j.1468-0262.2004.00528.x