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Testing Environmental Kuznets Curve (EKC) Hypothesis in ASEAN Countries: Evidence based on STIRPAT Framework with Cross-Sectional Dependency

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ABSTRACT

To date, many studies have been conducted to discover the factors influencing the decline in environmental quality. Like other countries, ASEAN countries also experience pollution issues in pursuing economic progress. The STIRPAT model is a framework often used to investigate the relationship between the related variables. Thus, this study uses data on CO_2 emissions, gross domestic products, trade openness, renewable energy and urbanization for seven selected ASEAN countries from 1995-2019. The aims of this study are to identify the factors that affect pollution among ASEAN countries, to model the long-term relationship between pollution and its related factors by considering interdependence among ASEAN countries and to investigate if EKC exists among the countries. The findings confirm that there is a cross-section dependency for ASEAN countries. The Westerlund cointegration test shows that the variables are cointegrated in the long run. Heterogeneous models that consider the effect of dependence between countries are used for estimation. The common correlated effects mean group (CCEMG) is seen as the best estimator compared to the augmented mean group (AMG) and mean group (MG) by having the smallest RMSE value. The estimated coefficient proves that there is a positive dependence on CO_2. Interestingly, this study also proves that the Environmental Kuznets curve (EKC) exists among ASEAN countries. It suggests that economic growth can initially exacerbate environmental problems, but it also implies that as countries continue to develop economically, they may have the resources and incentives to implement environmental policies and regulations that can mitigate ecological degradation. Overall, it can be concluded that there is a dependency or similar behaviour between ASEAN countries on the issue of environmental quality. Therefore, to achieve ecological sustainability, cooperation from neighbouring countries is necessary.

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1. Introduction

Pollution is a significant environmental challenge faced by almost all ASEAN countries. The rapid growth of cities and industries has led to a significant increase in air pollution levels. This is mainly caused by factors such as vehicle emissions, industrial activities, open burning and the burning of fossil fuels. People exposed to these pollutants may experience respiratory issues, cardiovascular diseases and other health problems. While these efforts are underway, it is crucial to maintain coordinated actions and sustained commitment to effectively combat pollution in the ASEAN region. A cleaner and healthier environment is everyone's responsibility, and it will need sustained commitment from organizations, businesses, and people to make this a reality.

Lessening to the critical impacts of global climate change, particularly carbon dioxide (CO_2) emissions, has become a major focus worldwide [1-3]. To date, to measure environmental degradation, scholars often use pollutants as the primary environmental indicator [4-6].

While previous studies have explored the relationship between pollution, energy and income, different methods including regression models and panel data analysis, the influence of urbanization and trade openness have not been a concern. A stable economic climate encourages investment, production and energy consumption, leading to increased environmental degradation. Conversely, economic downturns result in reduced economic activities and energy consumption, lowering pollution [7]. Governments can take advantage of economic downturns to implement ecological regulations at minimal cost, yielding immediate environmental benefits [8].

This study provides a contribution to the existing literature by investigating the impact the use of renewable energy, GDP, industrialization and urbanization on the environment in ASEAN countries by considering cross-sectional dependency among the countries. The STIRPAT framework has been broadly used in environmental studies to explore the relationship between human activities and various environmental issues, including pollution. Heterogeneous panel data estimation methodologies are employed to analyse the interaction. The study includes cross-sectional dependence (CSD) tests and cointegration tests to ensure appropriate analysis based on the nature of the dataset.

The objectives of this study encompass three main aspects. Firstly, it aims to investigate the factors that affect pollution among ASEAN countries. Secondly, to model the long-term relationship between pollution and its related factors by considering interdependence among ASEAN countries. Lastly, it aims to verify if the Environmental Kuznets Curve (EKC) exists among the countries. Considering the specific attributes of energy-related CO_2 emissions and drawing insights from relevant literature, our study extended the STIRPAT model. We introduced additional variables such as renewable energy and trade openness into the model. By incorporating these factors, we aimed to capture a more comprehensive understanding of the drivers behind CO_2 emissions in the ASEAN context.

The subsequent sections of this work are categorized into five parts. Section 2 offers an empirical review, delving into the existing literature. Section 3 focuses on the data collection process and methodology employed. Section 4 provides the results. Finally, Section 5 provides a comprehensive summary of the study's findings.

2. Literature Review

Increased concerns about environmental sustainability have arisen due to the rise in greenhouse gas emissions and worsening environmental problems resulting from development. The relationship between economic growth, environmental quality, and energy consumption has been extensively studied, with the EKC being one prominent theory. However, conclusive findings regarding this nexus remain elusive. Studies such as [9-11] argued that environmental degradation is not a significant concern during a country's economic development phase. On the other hand, [12] suggested that CO_2 emissions, energy consumption, and economic growth are interrelated, with a long-term equilibrium being reached after approximately 11 years. Long-run analyses conducted by [13] indicated that energy consumption and economic growth have a statistically significant impact on environmental degradation.

Recent research has increasingly recognized the crucial role of energy consumption as a determinant of environmental degradation, as highlighted in [14,15]. Energy consumption contributes to CO_2 emissions [16] and is a leading cause of environmental issues [17]. Similar findings regarding the long-term relationship between energy consumption and economic growth have been observed by [18-22]. For instance, [21] focused on leading emerging economies (South Korea, Russia, India and China), while [22] examined data from 188 countries.

Addressing the challenge of reducing energy consumption per capita while maintaining economic growth, [23] suggested that technological advancements, particularly the adoption of energy-saving technologies, offer potential solutions. However, the mass adoption of capital-driven production techniques in the industrial sector may lead to increased CO_2 emissions [24,25].

Previous empirical studies predominantly employed panel data regression techniques but often overlooked the cross-section dependence effect. Neglecting this effect can lead to inefficient and inconsistent estimates, as discussed by [26]. Correlated effects among regressors can further contribute to biased conclusions. Heterogeneous models investigating the relationship between energy and economic growth are relatively limited compared to other studies. For instance, [27] explored GDP and CO_2 emissions in middle-income economies from 1980 to 2012, finding that energy consumption played a crucial role in upper and lower-middle-income countries. [28], covering the period from 1975 to 2015, examined eight developing countries and discovered an inverted U-shaped relationship between energy intensity and industrialization/urbanization. Additionally, [29] investigated 20 OECD countries from 1870 to 2014 and identified a link between environmental degradation and growth using various estimators.

The STIRPAT model has been widely used in environmental studies to analyse the relationship between human activities and various environmental issues, including pollution. The flexibility of the STIRPAT model is one of its key advantages, as it allows for the incorporation, modification, and breakdown of various influencing factors that are relevant to the analysis [30]. Several past studies have employed the STIRPAT model to investigate different aspects of pollution [31-35]. [31] analysed selected Asian countries and highlighted the potential increase in CO_2 emissions due to carbon-intensive activities and industrialization. [32,34] extended the STIRPAT model in cross-country analyses, with [34] exploring different fossil fuel sources and their impact on the environment, while [36] identified a reduction in emissions among 18 developed countries due to increased renewable energy consumption and improved energy intensity. Furthermore, [33] studied the relationship between population, GDP, and emissions in Taiwan, finding that population growth had a positive effect on emissions while GDP had a negative effect. [35] discussed the differential impacts of population growth and economic growth on the environment based on a sample of 84 countries. Conversely, [36] found that energy consumption had a larger impact on environmental quality than economic growth and urbanization in China, utilizing a spatial-temporal approach not considered in previous STIRPAT literature. [37] investigated the impact of various driving forces on CO_2 emissions in several prominent ASEAN countries. The sample included Myanmar, Singapore, Malaysia, Thailand, the Philippines and Indonesia and the data covered the period from 1992 to 2016. The study employed panel data modelling techniques, specifically fixed effect regression estimation, random effect regression estimation, and pooled ordinary least squares (OLS) estimation. The dependent variable in the study was CO_2 emissions, while the independent variables among others are population, GDP, urban population and CO_2 intensity. The study's findings indicated that GDP, as a measure of affluence, and environmental patent count, as an indicator of technology, were important driving factors of CO_2 emissions in the ASEAN region.

Abbasi *et al.*, [38] used an extended STIRPAT model to examine the relationship between energy use, urbanization and carbon emissions in Asian countries. The results of the FMOLS and DOLS methods confirm the long-run direction among the variables. It is observed that energy consumption and urbanization have a positive impact on CO_2 emissions and economic output. Additionally, the study reveals that financial development has a negative effect on CO_2 emissions but a positive effect on economic growth. The Granger causality test suggests the existence of long-run causal relationships among the variables. Considering the interdependencies among countries, similar to our study, [39] employed the AMG and CCEMG estimators within the STIRPAT framework.

3. Data and Methodology

3.1 Theoretical Framework

The IPAT (Impact by Population Affluence and Technology) model, aimed to quantify the environmental impact of human-induced economic activity [40]. This model considered three fundamental variables: population size (P), affluence (A), and technology (T), which reflected the impact per unit of economic activity.

$$I_{it} = b_1 P^{b_2} A^{b_3} T^{b_4} e \tag{1}$$

In this equation, I represents the environmental impact for a country i at a time t. The variables P, A, T, and e represent to population size, affluence, technology and error term, respectively. The coefficients b_1, b_2, b_3 and b_4 quantify the influence of each variable on the environmental impact.

However, to enhance the model's ability for rigorous hypothesis testing, [41] redefined it as the STIRPAT model by incorporating stochastic elements. The STIRPAT model expanded upon the IPAT framework by allowing for a more comprehensive analysis of the relationships between population, affluence, technology, and their effects on the environment. It provided a mathematical structure to assess the environmental impact, utilizing additional variables and enhancing the model's statistical testing capabilities. By taking natural logarithm on left and right sides of IPAT model, the general form of the IPAT and STIRPAT model is expressed as:

$$LI_{it} = Lb_1 + LP^{b_2} + LA^{b_3} + LT^{b_4} + Le \tag{2}$$

The adoption of the $STIRPAT$ model facilitated more robust hypothesis testing and allowed researchers to investigate the complex interactions between population, affluence, technology and their implications for the environment. By employing this model, scholars gained a systematic and quantitative framework to analyze and comprehend the environmental consequences of human activities. The STIRPAT model has gained significant recognition due to its capacity for expansion to incorporate additional factors. As a result, it has become a widely adopted technique for investigating the impact of pollutant. In a study conducted by [42], the STIRPAT model was applied to examine the influence of urbanization on CO_2, specifically in the case of Malaysia. Similarly, [43] employed the STIRPAT model to explore the factors of CO_2 by conducting a study using non-renewable and renewable energy consumption in OECD countries [44].

The EKC as shown in Figure 1 holds significant relevance when examining the relationship between economic variables and pollution. Extensive discussions and debates have revolved around the concept of the EKC, which suggests that countries should prioritize economic growth as it is closely linked to CO_2 emissions in an inverted U-shaped curve. This implies that as a country initially experiences economic growth, there is a higher potential for an increase in CO_2 emissions. However, as the country continues along this trajectory, with advancements in technology and industrial competitiveness, emissions gradually begin to decline. Consequently, the environmentally destructive effects of economic growth eventually diminish. In the earlier stage of the EKC, economic growth contributes to an expansion in the size of the economy, leading to an increase in energy consumption that pollutes the environment. However, in the second stage of the EKC, the effects of technology and changes in the composition of economic growth come into play, influencing the quantity and type of energy consumption. These factors can have positive environmental effects, resulting in a decline in pollution levels. The research conducted in [45] has been instrumental in shaping the understanding of the EKC. Their findings highlight the dynamic relationship between economic growth and environmental impact. Furthermore, one of the recent studies, such as conducted in [46] have further contributed to the discourse surrounding the EKC, supporting the idea that as economies progress, they can achieve a decoupling of economic growth from environmental degradation. Overall, the EKC hypothesis underscores the importance of considering the long-term environmental implications of economic development.

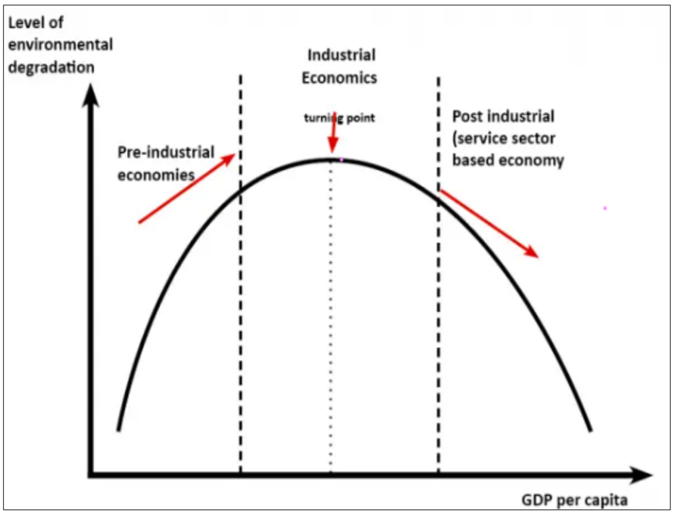

Fig. 1. Environmental Kuznets Curve (source: https://www.economicshelp.org)

3.2 Data Source and Description

In this study, a balanced panel data set comprising 175 observations is obtained from the World Development Indicators for a period spanning from 1995 to 2019. The selected countries include Cambodia, Indonesia, Malaysia, Philippines, Singapore, Thailand and Vietnam for which all the necessary data are available. The driving forces for CO_2 emissions, I (metrics tons per capita) considered are urban population, P (% of the total population), gross domestic product, A (per capita, constant 2015 USD), renewable energy consumption, T (% of total final energy consumption) and an extended factor, trade openness (% of GDP). Meanwhile, GDP squared is incorporated to test the EKC validity. Based on STIRPAT model, the extended version of the model in the logarithm form (L) can be written as:

$$LCO2_{it} = \beta_0 + \beta_1 LPOP_{it} + \beta_2 LGDP_{it} + \beta_3 LGDP^2{}_{it} + \beta_4 LREE_{it} + \beta_5 LTRD_{it} + e_{it} \quad (3)$$

where $CO2$ is carbon dioxide emissions, POP is urban population, GDP is gross domestic products, REE is renewable energy, TRD is trade openness and e is the error term. A finding that $\beta_2 > 0$ and $\beta_3 < 0$ would attest an EKC exists.

3.3 Regression Model

The analysis begins by conducting several statistical tests using STATA software to examine the properties of the variables. The presence of cross-section dependence (CSD) effect is confirmed using two different tests. The Lagrange Multiplier (LM) test, developed by [47] and the Pesaran CD estimator developed by [48], all confirm the existence of CSD. After confirming the presence of CSD, the stationarity of the series is assessed using second-generation unit root tests [49]. These tests account for the CSD effect when examining stationarity. The null hypothesis is formulated as no CSD (correlation) in residuals, while the alternative hypothesis assumes CSD (correlation) in residuals. By utilizing the Pesaran CD test, we can evaluate the stationarity properties of variables in panel datasets, while accounting for potential cross-section dependence and heterogeneity. This allows for a more robust analysis and accurate modelling of the underlying data. To determine whether the variables are integrated, [50] is employed. The all-panels option in the STATA package is utilized to test the null hypothesis of no cointegration against the alternative hypothesis of cointegration.

To analyse the relationship described in Eq. (3), heterogeneous estimators, namely mean group (MG), augmented mean group (AMG), and common correlated effect mean group (CCEMG) estimators, are employed. The AMG and CCEMG estimators consider the cross-section dependence (CSD) effect, while the MG estimator does not account for this effect.

All mean group type estimators follow a similar approach:

i. estimating a group-specific regression
ii. averaging the estimated coefficients across groups.

The MG estimator, developed by [51], allows for parameter heterogeneity by separately estimating OLS regressions for each panel. The average of the coefficients is then calculated to estimate the mean parameters across groups. This estimator exhibits consistent performance when the sample size and time-period dimension are sufficiently large. The CCEMG estimator, introduced by [52], is an extension of the MG estimator. Unlike the MG estimator, the CCEMG estimator takes into account the CSD effect and offers robustness against slope heterogeneity and endogeneity. Moreover, the CCEMG estimator is robust to structural breaks, non-stationarity, and non-cointegration, even for smaller sample sizes. In the CCEMG estimator, the average of the variables is calculated for the entire panel, and each equation includes the average cross-section terms of both y and x. The AMG estimator, originally introduced by [53] and further developed by [54], is specifically designed to address both CSD and slope heterogeneity. The AMG estimator incorporates a "common dynamic process" variable. The AMG estimator is unbiased and remains efficient regardless of the dimensions of the sample and time-period, making it robust to changes in degrees of freedom.

4. Empirical Results

The presence of the cross-section dependence (CSD) effect is assessed through the utilization of CSD tests. The finding in Table 1 indicates that the Breusch-Pagan LM statistic reject the null hypothesis of no CSD effect in the ASEAN countries. Breusch-Pagan LM is preferable as N<T. These results suggest the existence of the CSD effect in the region. Due to the dependency observed, the first-generation panel unit root test is deemed inappropriate for use. Hence, we proceed with the second-generation panel unit root test to account for cross-sectional unit dependence.

Table 1
Cross-Sectional Dependence Test Results

Test	Statistic
Pesaran CD	-0.119
Breusch-Pagan LM	131.031

The results of the panel unit-root test based on Pesaran's CIPS method is presented in Table 2. After differencing, when no lag is considered, the test statistics for all variables indicate that the null hypothesis of a unit root in the series should be rejected. Thus, we can conclude that the variables are integrated of order 1 or I(1).

Table 2
Second Generation Panel Unit Root Test Results

	Statistic			
Lag	0	1	2	3
	Levels			
LCO_2	0.763	0.742	1.723	2.784
LPOP	-0.428	-0.268	-0.427	0.926
LGDP	2.116	1.757	-0.296	2.146
LREE	1.600	0.256	1.327	0.880
LTRD	-0.052	0.270	-0.369	3.523
	First difference			
LCO_2	-5.855***	-3.516***	-0.910	0.499
LPOP	-0.757*	4.554	2.003	0.047
LGDP	-3.133***	-3.777***	-2.711***	1.404
LREE	-5.196***	-2.560***	0.013	0.596
LTRD	-6.809***	-2.783***	-3.957***	1.047

Subsequently, as all variables are identified as I(1), we proceed to examine if there is cointegration among variables. Table 3 displays the outcomes of the Westerlund (2005) cointegration test. The result in the table provides evidence to reject the null hypothesis of no cointegration. Therefore, we can conclude that there is a cointegrated relationship among the panels. Consequently, the application of heterogeneous models is justified.

Table 3
Westerlund (2005) Cointegration Test

	statistic
Variance Ratio	-1.3961*

Table 4 presents the estimation results from the heterogeneous models. The coefficients of the population, GDP, GDP square, renewable energy and trade openness demonstrate consistent signs across all three estimators, indicating the direction of their effects on environmental degradation. Among the three estimators, the CCEMG estimator exhibits the smallest Root Mean Squared Error (RMSE) value of 0.0230, indicating the lowest forecast error and thus better performance.

Focusing on the results obtained using the CCEMG estimator, it is observed that Mean_LCO_2 (0.7558) shows a positive and significant effect on cross-section dependence, implying interdependence or similarity in the behaviour of emissions across countries. Ignoring this effect can lead to biased and inconsistent estimations. Regarding the main effect coefficients, trade openness (LTRD) contributes to a significant impact on environmental issues. The coefficient of LTRD suggests that a 1% increase in trade leads to a 0.1049% decrease in CO_2 emissions. Trade openness facilitates the transfer of technology and knowledge across borders. Advanced economies often invest in research and development to develop cleaner and more efficient technologies. Through trade, these technologies can be transferred to less developed countries, enabling them to adopt cleaner production methods and reduce pollution. For instance, the transfer of renewable energy technologies can help countries shift from fossil fuel-based energy production to cleaner and sustainable alternatives [55]. Moreover, it is interesting to note that the coefficients for LGDP and LGDPSQ are positive and negative, respectively, confirming that an EKC exists among the countries.

Comparing the estimators, similar as found in [56], the MG estimator (without considering the cross-section dependence effect) shows higher RMSE compared to the estimators that consider the CSD effect (AMG and CCEMG), further emphasizing the relevance of incorporating cross-section dependence in the analysis.

Table 4
Estimation Results

	MG	CCEMG	AMG
Long-run impacts			
LPOP	1.7580	1.9088	-0.0669
	(1.3944)	(1.8746)	(0.1122)
LGDP	7.8912**	9.4509	6.6437
	(3.6210)	(9.0964)	(4.7613)
LGDPSQ	-0.3689	-5.5809	-0.3771
	(0.2253)	(0.4980)	(0.2997)
LREE	-0.4605**	-1.1897	-0.2881**
	(0.2240)	(0.1289)	(0.1409)
LTRD	-0.0568	-0.1049*	-0.0721**
	(0.0509)	(0.0546)	(0.0359)
constant	-26.5104	-57.7955	-27.3399
	(17.5282)	(48.8441)	(26.1043)
trend	0.0057	-0.0156	-0.0021
	(0.0087)	(0.1309)	(0.0144)
$\hat{\mu}$ ·			0.8091*
			(0.4362)
Mean_LCO_2		0.7558**	
		(0.3425)	
Mean_LPOP		-1.3516	
		(9.9121)	
Mean_LGDP		0.0894	
		(2.7310)	
Mean_LGDPSQ		0.0034	
		(0.2144)	
Mean_LREE		0.1863	
		(0.2757)	
Mean_LTRD		0.1494	
		(0.1126)	
RMSE	0.0347	0.0230	0.0284

4. Conclusion

This study aims to investigate the long-term factors that affect pollution among ASEAN countries by considering interdependence and verifying if the EKC exists. The finding from heterogeneous models provides valuable insights into the relationship between various factors and environmental degradation and cross-section dependence among selected ASEAN countries. The results showed that an extended factor of the STIRPAT model, trade openness has a significant and negative impact on CO_2 emissions, indicating that increased trade can contribute to reducing pollution levels. This suggests that international trade can serve as a mechanism for the transfer of cleaner technologies and practices, leading to improved environmental outcomes.

Additionally, the presence of a positive and significant cross-section dependence effect for CO_2 emissions, suggests interdependence or similarity in the behaviour of emissions across countries. Ignoring this effect may lead to biased and inconsistent estimations, underscoring the importance of considering cross-section dependence in future research. The study also highlights the existence of the EKC pattern. This suggests that as countries experience economic growth, there is an initial increase in environmental degradation, followed by a decrease as they reach higher levels of development and implement more sustainable practices.

Comparing the different estimators, the MG estimator, which does not consider cross-section dependence, exhibits higher RMSE values compared to the estimators that account for the CSD effect (AMG and CCEMG). This emphasizes the importance of incorporating cross-section dependence in the analysis to obtain more accurate and reliable results. Overall, these findings contribute to the understanding of the relationship between factors affecting environmental sustainability. They have implications for policymakers such as promoting trade policies that encourage the adoption of cleaner technologies and practices, facilitating sustainable development, and addressing environmental challenges at a global level. Efforts include strengthening environmental regulations, promoting sustainable practices, encouraging technological innovation, enhancing waste management systems, and raising awareness about the importance of environmental protection. However, further coordinated efforts and continued commitment are necessary to effectively combat pollution in the ASEAN region and ensure a cleaner and healthier environment for all.

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