Validating the Environmental Kuznets Curve: Evidence from ASEAN's Economic Growth, Renewable Energy, and Carbon Emissions

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Abstract. This study investigates the nexus between economic growth, foreign direct investment (FDI), technological advancement, household consumption, and greenhouse gas emissions (GHG) among ASEAN countries. The Environmental Kuznets Curve (EKC) hypothesis suggests an inverted U-shaped relationship between environmental degradation and economic development, signifying that pollution levels primarily increase with economic growth but decline after reaching a turning point. Employing panel data spanning from 1990 to 2022 for seven ASEAN countries including Cambodia, Brunei, Malaysia, Indonesia, Thailand, Philippines and Vietnam, this study uses Pooled Mean Group (PMG) analysis to scrutinise the short-run and long-run relationships among the variables. The findings provide support for the validity of the EKC hypothesis in the ASEAN region, signalling the existence of an inverted U-shaped relationship between economic growth and GHG. In the short run, FDI and economic growth were found to increase emissions, while in the long run, growth in technological advancements and gross production were correlated with a reduction in GHG. The findings offer significant insights particularly for policymakers among ASEAN countries to formulate effective strategies that balance technological advancement, FDI attraction economic growth and environmental sustainability, while also emphasising the importance of promoting sustainable consumption patterns.

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1 Background of the study

Scholars and policymakers have given extensive attention to the nexus between environmental quality and economic development. The Environmental Kuznets Curve (EKC) hypothesis was formulated by Kuznets in 1955, which held that the process of economic expansion would initially lead to deterioration and then the reduction in environmental quality with increased economic development. This U-shape is of great importance for understanding the ecological implications of economic growth.

In the past few decades alone, ASEAN has emerged as one of the most vibrant economies, growing at a rate that can only be dubbed meteoric. But this economic boom brought a high price – increased GHG emissions, leading to an unprecedented level. However, all these countries need to seek their continued economic growth and development, and as such, face a major dilemma of needs-based growth and environmental impact.

The link between rising economic growth and increasing degradation of the environment has garnered extensive research, frequently under the auspices of the so-called 'EKC hypothesis. The main contention is that economic development exhibits an inverted U-shaped relationship with environmental quality [1]. This hypothesis, nevertheless, is still in debate concerning its applicability to the ASEAN countries, considering their peculiar national development path and policy milieu.

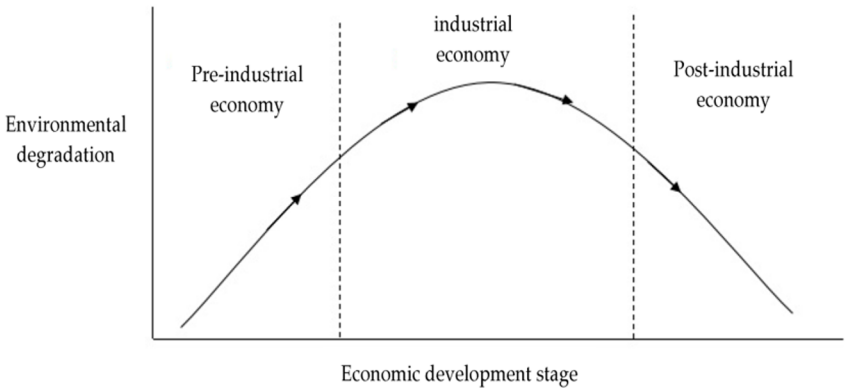

Fig. 1. EKC Hypothesis
Source: Othman et al. [1]

Technological developments have recently emerged as a solution to the growth-environment dichotomy. The indicators of the Technology Achievement Index that defines the underpinning technological progress of a country have been linked to economic development and ecological outcomes. On the same note, FDI has also been seen to have a very close connection to the level of economic development in ASEAN countries. However, there are several other environmental effects associated with FDI that scholars have not effectively explained.

The present study will contribute to GDP growth, greenhouse gas emissions, technological development, foreign direct investment and household consumption in ASEAN countries. The study has validated the EKC hypothesis in ASEAN countries to investigate the relationships between economic growth, renewable energy consumption, and carbon emissions. Analyses of such patterns guide us in participating in informed policy-making for long-term sustainability in the area.

The study's objective is to contribute to understanding sustainable economic development in an ASEAN context due to a growing body of literature addressing this theme It would

assist in the formulation of rather scarce knowledge on the relationship between growth and environment in the region taking into account variables like technology, FDI and consumption pattern. These results will offer insights of values to policymakers, researchers, and all stakeholders in shaping the future of the ASEAN region's economy and environment.

The paper is arranged as follows: Section two further explains the EKC origins, followed by the methodology section. Section four presents the study's findings and section five explains the study implications of the models.

2 Literature review

The developed hypothesis of the environmental Kuznets curve was initiated by Grossman and Krueger (1991), who state that there is an inverted 'U' shaped relationship between the level of economic development and the degree of environmental degradation. The EKC hypothesis asserts that environmental degradation rises with the level of income per capita at the initial stages of a country's development but declines once the country attains beyond a certain threshold level of development cross-section. The EKC has been the object of significant attention in a number of different areas, particularly the rapidly expanding ASEAN area.

There has been a study made in the context of ASEAN emphasizing the EKC hypothesis, which asserted that there is a relation between economic growth, CO2 emissions, and energy consumption (EC). The later study [2] for ASEAN-5 countries (Indonesia, Malaysia, Philippines, Singapore, and Thailand) from 1980 to 2012 empirically tests the relationship between energy consumption and environmental descriptor. Their findings also support the EKC hypothesis, where economic growth increases CO2 emissions at low-income levels per capita. Still, this relationship switches direction for countries with higher levels of development.

There is a paradigm shift and noteworthy considerations associated with the application of renewable energy in the establishment of the EKC framework. [3] examined the effect of Renewable Energy Consumption in those countries for carbon dioxide emissions between 1995-2014 in ASEAN countries. Based on their findings, they proposed that using more renewable energy means lowering carbon emissions hence facilitating a shift of the country to the downward part of the EKC. Nonetheless, not all the research has directly validated the assertion made of the EKC hypothesis in the case of ASEAN countries.

This heterogeneity in the economic structures and development stages of ASEAN members is one reason why testing for evidence of the EKC hypothesis is so difficult. The relationship between economic growth, energy consumption, and CO2 emissions over the period of 1971–2008 for Indonesia, Malaysia, and the Philippines is examined by [4]. In fact, they derived evidence for the EKC hypothesis in Malaysia but not in Indonesia or the Philippines, suggesting a substantial regional heterogeneity. Some recent studies related to the above theoretical underpinnings include [5], which looked deeper into the effect of globalization, financial development, and energy consumption on environmental degradation in ASEAN-5 countries from 1980 to 2014. They supported the EKC hypothesis in their study and argued for including additional factors alongside economic growth to explain patterns of environmental degradation. A number of works have been dedicated to exploring this relationship in the context of ASEAN countries. [6] studied the impact of economic development on environmental pollution in Asia-Pacific Economic Cooperation countries, where they affirmed the EKC hypothesis. Likewise, [7] examined the influence of economic growth in exacerbating climate change in emerging ASEAN countries.

On the other hand, the flow of the causality between GDP growth and greenhouse gas emission has not been clearly established. Some of the literature presented in this paper shows the positive correlation between economic growth and emissions while others deny the

relationship asserting that it cannot be simplified. For instance, [8], a recent study employing a quantile analysis of a quantile-on-quantile-based approach to testing the energy consumption and economic growth relationship among the world's leading energy consumers discovered different non-linearities in different intervals or quantiles.

The TAI works as an indicator of a country's technological advancement. Technological progress and the pattern of the growth of the GDP have been researched extensively throughout the world, and most of the researchers have noted positive results. Similarly, in [1], the authors confirmed that enhancement in technology along with Ascend in the domestic savings to invest in research and development made the environmental quality in ASEAN countries better in the long run. This implies that technological advancement and development processes and the growth of the economy and the environment are interconnected and always interact in a very close manner.

[9] discussed the relationship between environment regulation, economic growth and environment sustainability for South Asian countries with heeding the significance of technological advancement. The authors discovered that technological advancement, proxied by environmental patents, was an important determinant of both economic development and environmental quality.

The effects of FDI on economic growth have been well-researched, particularly within the ASEAN countries. Several authors have noted a complexity in FDI and GDP growth concerning the magnitude and conditions involved. [10] explored the effects of economic development, globalization, and urbanization on sustainable development in the sub-region of Africa. In their study, they examined the factors that affect economic growth propelled by FDI and the effects of FDI on the environment. [11] look at the influence of technological innovation, FDI, and financial development on CO2 emissions in G8 countries. Their research was centred on emissions; however, they adequately explained the interaction between FDI, economic growth, and environmental effects.

Household spending on goods and services is one of the main components of the expenditure approach, and it contributes significantly to overall economic growth. GDP and household consumption correlated, though the type of that correlation was vital to the environment. In this vein, Li and Wei (2020) analyze the influence of financial development, economic growth, and carbon emissions in China. While not applicable to household consumption, their work did show the role domestic demand played in both economic development and environmental pressures.

The literature provides evidence that the policymakers in ASEAN countries need a comprehensive strategy for sustainable economic growth. An integrated approach should be adopted, which evaluates the intricate links between technological progressions and environmental outcomes in conjunction with FDI and household consumption. Further research may explore non-linear associations between variables in the model. It could include analyses of the long-term and short-term effects of these variables on GDP growth as well as environmental outcomes in ASEAN countries.

Given the rich literature on different works that studied GDP growth either separately or jointly with gas emissions, technological progress, FDI and household consumption within different economies (including ASEAN countries), conducting an extensive account of these studies is recommended. This, in turn, supported a deeper understanding of the factors that promote sustainable economic growth within the region.

3. Methodology

3.1 Data sources and description of variables

The sample period for the study was limited to 32 years (from 1990 to 2022) based on the data available to measure the TAI and it included 7 ASEAN: Brunei, Cambodia, Indonesia, Malaysia, Philippines, Thailand, and Vietnam. Table 1 shows the selected variables and the proxies used to measure each variable.

Table 1. Key Variables

Variable Name	Proxy and the calculation mechanism
Greenhouse gas emission (CO2E)	Total greenhouse gas emissions (kt of CO2 equivalent)
GDP growth (gdp_grw)	GDP per capita growth (annual %)
Foreign Direct investments (FDI)	Foreign direct investment, net inflows (% of GDP)
Household final consumption (HC)	Households and NPISHs final consumption expenditure (% of GDP)
Technological Advancement (Tech)	Fixed telephone subscriptions (per 100 people)

3.2 Model specification

$$CO2E_{it} = \propto_0 + \propto_1 Gdp\_grow_{it} + \propto_3 FDI_{it} + \propto_4 HC_{it} + \propto_5 Tech_{it} + \varepsilon_t \quad (1)$$

Where; CO2E indicates the greenhouse gas emission while gdp_grow, FDI, HC and Tech represent the economic growth, Foreign Direct Investments, Household Final Consumption, and Technological Advancements respectively. While ε shows the error term. Since the study used panel data analysis with unrestricted specification, 'i' denotes the cross-sections, and 't' represents the respective period.

The three-panel ARDL models, Pooled Mean Group (PMG), Mean group, and Dynamic Fixed Effect, were used in the study as the primary analysis tools to look at the relationship between explanatory and regressor variables over the short- and long-run. The study used the Breush-Pagan (1980) LM test, scaled LM test, bias-corrected scaled LM test, and Pesaran (2004) as its key methodologies because the choice of data analysis method depends on whether the data set contains cross-sectional dependencies. The study occupied the Hausman test to confirm the slope homogeneity and finalize the best-fitted model among PMG, MG, and DFE. If test results show that the P-value is more than 0.05, the study selects PMG as the most appropriate technique to present the relationship between explanatory and regressor variables [12].

4 Results

4.1 Descriptive statistics

The summary statistics of the sample have been presented in Table 2. The central tendency values indicate the statistical position of the data set. Test results confirm that economic growth shows a negative tail while other variables show positive skewness. Furthermore, ghg, gdp_grw, and fdi show the leptokurtic distribution meanwhile, hfc and ta show the platykurtic distribution.

Table 2. Descriptive statistics

	N	Mean	Max	Mini	Std. Deviation	Skewness	Kurtosis
	Stat	Stat	Stat	Stat	Stat	Stat	Stat
CO2E	231	11.46	13.84	8.46	1.47	1.53	4.54
Gdp_grow	231	4.38	14.52	-34.81	4.69	-3.04	23.75
FDI	231	5.59	31.62	-2.76	6.68	1.83	5.87
HC	231	54.71	101.12	12.78	19.03	0.01	2.61
Tech	231	13.60	48.01	0.04	12.93	0.98	2.97

(Source. E-view results sheet)

4.2 Correlation

Table 3 illustrates the correlation among the variables. Test results indicate that household consumption and economic growth have a positive association with greenhouse gas emissions while technological advancement and foreign direct investments follow an inverse correlation.

Table 3. Correlation matrix

	ghg	gdp_grw	hc	ta	fdi
CO2E	1				
Gdp_grow	0.1118	1			
HC	0.2856	0.1510	1		
Tech	-0.2989	-0.0139	-0.7046	1	
FDI	-0.2899	0.1519	-0.2403	0.5975	1

(Source: E-views output)

4.3 Multi collinearity test

Table 4 shows the results for multicollinearity among the variables. Table stats show that all the variable values are well below the critical value (5) and the tolerance values are greater than 0.2. Therefore, Table 4 confirms that there is no multicollinearity among the variables.

Table 4. Multi Collinearity Test

Variable	VIF	1/VIF
Gdp_grow	3.24	0.308993
HC	2.26	0.443193
Tech	1.77	0.565746
FDI	1.06	0.939425
Mean VIF	2.08	

(Source. STATA/MP 14.0 output)

4.4 Cross-sectional dependency

The study used Breush-Pagan's (1980) LM test, Pesaran's (2004) scaled LM test, Baltagi, Feng, and Kao's (2012) bias-corrected scaled LM test, and Pesaran's (2004) CD test to examine the cross-sectional dependency. Table 5 shows the test results where the null hypothesis was "there is no cross-sectional dependency" among countries. Table values confirm that there is a cross-sectional dependency.

Table 5. Cross-sectional dependency

	Breusch-Pagan LM	Pesaran scaled LM	Bias-corrected scaled LM	Pesaran CD
CO2E	589.5449***	87.72838***	87.61900***	24.24478***
Gdp_grow	145.3923***	19.19415***	19.08478***	8.9857***
HC	174.1343***	23.62914***	23.51977***	1.162872
Tech	131.1995***	17.00415***	16.89478***	6.850001***
FDI	53.53303***	5.019955***	4.910580***	0.489958

***, ** and * show significance at the 1%, 5% and 10% levels, respectively.
(Source. E-views output)

4.5 Unit root test

Table 6 presents the unit root test results of the data set. Since there is a cross-sectional dependency in the panel data set, the study utilized the second-generation unit root test of CIPS. CIPS statistics highlight that all the variables get stationary at their 1st difference. Therefore, it gives direction to follow the panel ARDL model to analyze the long-run and short-run effects.

Table 6. Unit root test

Variable	CIPS	
	Level	First Difference
CO2E	-2.13461	-3.94784***
Gdp_grw	-2.71652***	-5.81013***
HC	-1.32629	-3.99561***
Tech	-0.31374	-6.35528***
FDI	-3.16773***	-4.32852***

***, ** and * show significance at the 1%, 5% and 10% levels, respectively.
(Source. E-views Output)

4.6 Panel data estimation

The study used the three types of dynamic panel ARDL models named; Pooled Mean Group (PMG), Mean Group (MG), and Dynamic Fixed Effect (DFE) to measure the short-run and long-run effects. The results are presented in Table 7. To identify the best-fitted model, the study followed the Hausman test statistics which are presented in Table 8.

Table 7. Panel cointegration

CO2E	MG	PMG	DFE
		LONG RUN	
CO2E	0.0251217***	-0.007243***	0.0615559*
HC	(0.0059835)	(0.0029348)	(0.0339899)
	-0.0004482	0.0332433***	0.0043011
	(0.0070642)	(0.0030147)	(0.0094293)
Tech	0.0207722	-0.015337***	0.019866
FDI	(0.0231225)	(0.0025357)	(0.0197187)
	0.2742038	-0.3686047***	0.1756772
	(0.1975677)	(0.1093098)	(0.39222)
		SHORT RUN	

Speed of adjustment	-0.7607125***	-0.0947556***	-0.3963228**
	(0.1599503)	(0.0391814)	(0.183418)
CO2E	-0.0046772	0.0342747***	-0.0000861
HC	(0.0028524)	(0.006053)	(0.0017262)
	-0.0012529	-0.0047358	0.0007599
	(0.0037194)	(0.0024295)	(0.0013211)
Tech	0.881202	1.065573	0.0534262
FDI	(1.163925)	(1.020416)	(0.0386532)
	0.0798162	0.2622721*	0.025282
	(0.0699628)	(0.1512526)	(0.0541858)
Number of countries	7	7	7
Number of observations	231	231	231

***, ** and * show significance at the 1%, 5% and 10% levels, respectively.
Values in parenthesis indicate the standard error (Source. STATA/MP 17.0 output)

Table 8. Hausman Test

Test	Chi2 value	Probability value	Decision
MG vs PMG	5.41	0.1581	PMG is appropriate
MG vs DFE	0.00	1.000	PMG is appropriate

(Source. STATA/MP 17.0 output)

Table 8 presents the Hausman test statics and proves that PMG is the best-fitted model to present the influence of explanatory variables on the regressor since it assumes that the long-run coefficients are identical but differ across the cross sections in the short-run. Furthermore, PMG is treated to heterogeneity bias and can identify the long and short-run effects with the convergence of the parameters.

The results suggest that all the variables significantly affect greenhouse gas emissions in ASEAN countries. In addition, economic growth and foreign direct investments cause to increase the greenhouse gas emissions but neither technological advancement nor household consumption show a significant effect on greenhouse gas emissions. However, in the long run, all the explanatory variables have a significant influence on the response variable. Meanwhile, household final consumption has a significant affirmative effect on greenhouse emissions yet other variables have an inverse influence over the dependent variable.

Therefore, the results reveal that in the long run, the improvement in gross production and technology facilitate the economies to move toward renewable and eco-friendly energy sources. In addition, foreign investments towards the development of the economy lead to investment in environmentally friendly projects. Therefore, the test results confirm that the study a line with the EKC hypothesis since in the short-run, countries are highly focused on economic development through industrial sector development rather than concerning the environmental impact.

Furthermore, the speed of adjustment (convergent coefficient) indicates the time lag to recover the environmental damage made by the macroeconomic variables. According to test statistics, it takes more than 1 year to recover the short-run effect of economic growth and Foreign Direct Investments over greenhouse gas emissions.

5 Conclusion

The study indicated that FDI first increases emissions but later invests in green projects. This shift supports the EKC idea that economic development can sustain the environment. Interestingly, household final consumption had a beneficial long-term influence on greenhouse gas emissions, suggesting a policy intervention to promote sustainable consumption. The speed of adjustment coefficient shows that economies require over a year

to recover from short-term environmental damage from economic expansion and FDI. To reduce short-term consequences, proactive environmental policies are crucial. The findings have major consequences for ASEAN policymakers. Economic growth is vital, but so is accelerating the shift to greener technology and promoting sustainability. Policies that stimulate green FDI, renewable energy technology innovation, and sustainable consumption could assist ASEAN countries navigate the EKC faster and achieving the turning point. Future studies could examine how technical advances and FDI improve the environment over time. Regional cooperation's participation in this transformation may also help other developing regions. In conclusion, our study supports the EKC theory in ASEAN countries, bringing optimism for economic development and environmental sustainability. It emphasizes the need for long-term planning and tailored strategies to balance regional expansion and environmental protection.

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