The Energy-Emission-Growth Nexus in ASEAN: A Heterogeneous Panel Analysis of Renewable Transition and Economic Outcomes

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Abstract. This study examines the relationships between renewable energy, fossil fuel consumption, CO_2 emissions, and economic growth in ASEAN. To account for significant heterogeneity among member states, a panel data approach captures country-specific effects, offering a nuanced perspective on the energy transition's economic implications. Analyzing data from Indonesia, Malaysia, Thailand, Singapore, the Philippines, and Vietnam (2000-2023), a panel regression model is estimated. Statistical tests confirm the Fixed Effects Model (FEM) as optimal, controlling for unobserved national characteristics. The findings reveal significant heterogeneity. Aggregate analysis shows renewable energy correlates more strongly with GDP per capita than fossil fuels, while CO_2 emissions exhibit a negative relationship. Country-level analysis reveals critical divergences: Vietnam demonstrates a decoupling pathway with lower emissions alongside higher growth, whereas Indonesia and the Philippines show negative coefficients for renewables, suggesting cost-related barriers limit their economic benefits. By explicitly modelling heterogeneity, this study advances beyond homogeneous panel assumptions that mask critical disparities. The results provide tailored insights into diverse ASEAN energy-economic realities, highlighting the ineffectiveness of uniform transition strategies and underscoring the need for context-specific policies to synergize economic and environmental objectives.

Keywords. Energy Transition, Environmental Kuznets Curve (EKC), ASEAN Economics, Heterogeneous Panel Data, Carbon Emissions.

1. Introduction

The global threat of climate change is creating unprecedented pressure for countries to decarbonize their economies without sacrificing economic growth. This dilemma is particularly challenging for the Southeast Asian region (ASEAN), where rapid economic growth is still heavily dependent on fossil fuels [1]. The dominance of conventional energy—

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such as coal in Indonesia and oil and gas in Singapore, Vietnam, and Thailand—has made the energy transition a complex and urgent agenda [2]. Research suggests that a gradual transition from non-renewable to renewable energy sources is possible for countries in the long term [3]. In this context, renewable energy emerges as a crucial solution to break the link between economic growth and carbon emissions [4]. ASEAN's transition efforts can be driven by innovation, given the critical role of technological innovation in this process [5]. This transition is highly dependent on technological innovation. Patents in the field of energy technology are often used as a proxy to measure the progress of such innovation [6]. While the link between technological innovation and environmental performance has been examined globally, its significance in the ASEAN context is still not compelling [7]. This is likely due to research capacity gaps, differing national policies, and barriers to technology transfer among member countries [8].

The bulk of existing literature on the energy-environment-economy relationship in ASEAN have used individual *time series* approaches [9] or panel data models that assume homogeneity across countries. This approach has significant limitations because it obscures the striking structural and policy heterogeneity within the ASEAN region [10]. This methodological limitation reduces the efficacy of studies on ASEAN member states, as it cannot adequately account for the specific energy policy issues and structural gaps present within the region [11]. Consequently, the findings from these studies may fail to capture the complex realities and specific policy gaps in each country. To address this shortcoming, this study investigates the dynamic relationship between energy consumption (both fossil and renewable), economic growth (GDP), CO_2 emissions, and technological innovation by employing a panel data approach explicitly designed to capture cross-country heterogeneity. By focusing on six core ASEAN economies—Indonesia, the Philippines, Malaysia, Thailand, Singapore, and Vietnam—over the period 2000–2023, this research provides a more granular and contextual analysis. Our primary contribution lies in applying a methodological framework that enables more valid comparisons across heterogeneous countries, thus generating more targeted policy recommendations

This study was conducted to analyze the dynamic relationship between energy consumption (fossil and renewable), economic growth (GDP), CO_2 emissions, and technological innovation within a panel data framework [12]. The Environmental Kuznets Curve (EKC) theory serves as the foundational framework and will be tested in the unique ASEAN context to examine whether the relationship between GDP and emissions aligns with the theory. This aims to verify the hypothesis that emissions increase alongside economic growth up to a certain turning point, after which they begin to decline [1], [11]. Furthermore, Growth Theory expanded to incorporate innovation, along with the Energy-Economy-Environment (3E) framework, serves as the foundation for analyzing multi-sectoral interactions among the key variables [13]. Therefore, this study not only addresses a methodological gap but also provides robust empirical evidence for established theories within the context of a rapidly developing region.

2. Methods

2.1 Research Design

This study aims to investigate the complex dynamics between energy, environment, and economic growth in Southeast Asia. Specifically, it analyzes the impact of three key variables—renewable energy consumption, non-renewable energy consumption, and carbon dioxide (CO_2) emissions—on economic prosperity as represented by Gross Domestic Product (GDP) per capita. The research focuses on six core ASEAN member countries: Indonesia, the Philippines, Malaysia, Thailand, Singapore, and Vietnam. These nations were selected based on their diverse economic and energy profiles, ranging from newly industrialized economies such as Thailand and Malaysia, to financial hubs like Singapore, and rapidly growing economies like Vietnam and Indonesia. Consequently, this study seeks to provide a comprehensive overview of how energy transition and environmental impacts interact with economic development in this strategic region.

To achieve these objectives, this study employs a quantitative approach using credible secondary data. The analysis utilizes panel data, combining time-series and cross-sectional dimensions from the six countries spanning the period 2000 to 2023. Primary data sources are obtained from two reputable institutions: the World Bank's *World Development Indicators* (WDI) for GDP per capita and CO_2 emissions data, and *the Energy Institute's Statistical Review of World Energy* (2025 edition) for renewable and non-renewable energy consumption data. The inclusion of data up to 2023 ensures the study's findings remain highly current and relevant to contemporary conditions. The main analytical method applied is panel data regression using the *Ordinary Least Squares* (OLS) technique. To ensure the most appropriate and robust model specification, a series of rigorous statistical tests will be conducted (Fig. 1). Therefore, the testing model employed in this study is formulated as shown in Equation 1.

$$GDPC_{it} = \beta_0 + \beta_1 RENC_{it} + \beta_2 FOSC_{it} + \beta_3 CO2_{it} + \upsilon_i + \varepsilon_{it} \quad [1]$$

In this panel equation, $GDPC_{it}$ serves as the dependent variable (Y), representing GDP per capita for country (i) in year (t). The independent variables (X) consist of $RENC_{it}$ (renewable energy consumption), $FOSC_{it}$ (non-renewable energy consumption), and $CO2_{it}$ (carbon dioxide emission levels), each with their respective coefficients (β_1, β_2, and β_3) to be estimated to determine the magnitude and direction of their effects. The component υ_i captures unobserved country-specific individual effects (such as cultural or institutional policy factors), while ε_{it} represents the error term accounting for unforeseen disturbance factors. Prior to conducting the final estimation, the most appropriate model specification—whether the Fixed Effects Model (FEM) or Random Effects Model (REM)—will be determined through the Hausman test. This test essentially examines whether the individual effects (υ_i) are correlated with the independent variables, thereby ensuring the accuracy and consistency of the resulting estimators.

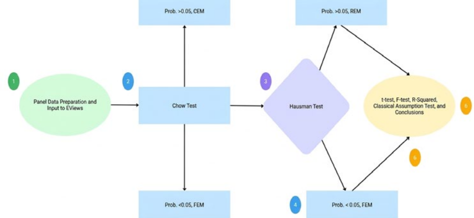

Fig. 1. Testing Flowchart

More comprehensively, the analytical procedure begins with Model Selection Tests among the Common Effect Model (CEM), Fixed Effect Model (FEM), and Random Effect Model (REM) using the Chow Test and Hausman Test [14]. Once the best model is identified, the subsequent step involves testing the overall statistical significance of the model using the F-test and the significance of each independent variable's coefficient using the t-test. The coefficient of determination (R-squared) will be calculated to measure the proportion of variation in GDP per capita that can be explained by the three independent variables. Furthermore, to ensure the regression results are unbiased and satisfy the Best Linear Unbiased Estimator (BLUE) criteria, this study will conduct Classical Assumption Tests, specifically the multicollinearity test to detect high correlation among independent variables and the heteroscedasticity test to examine the homogeneity of error term variances [15], [16].

Finally, as an in-depth analysis, this study will observe and interpret the regression coefficients for each of the six countries to understand the specific effects of the X variables on the Y variable within each national context.

2.2 Data specifications

The study utilizes secondary data from the World Bank's *World Development Indicators* for GDP per capita in USD and CO_2 emissions per capita in metric tons. Additionally, data on renewable and non-renewable energy consumption (measured in kWh) are sourced from the *Energy Institute's Statistical Review of World Energy* (2025 edition). Renewable energy consumption encompasses hydropower, wind, solar, geothermal, wave and tidal, and bioenergy excluding traditional biofuels, while non-renewable energy represents fossil fuel-based generation. Both energy variables are expressed in per capita terms, enabling this study to measure the environmental impact generated and utilized by each individual within the respective countries. The variable descriptions and data sources are presented in Table 1.

Table 1. Operational Definition of Variables

Variable Name	Variable Code	Source
GDP per capita (current US$)	GDPC	World Development Indicators (WDI)
Carbon dioxide (CO2) emissions excluding LULUCF per capita (t CO2e/capita)	CO2	World Development Indicators (WDI)
Renewables per capita (kWh - equivalent)	RENC	Energy Institute - Statistical Review of World - Energy (2025); Population based on various sources (2024) – [17]
Fossil fuels per capita (kWh)	FOSC	Energy Institute - Statistical Review of World - Energy (2025); Population based on various sources (2024) – [18]

3. Result and Discussion

3.1.Model Selection Test

Model selection was conducted using two statistical tests: the Chow test and Hausman test. This approach was adopted because the results consistently showed significance levels below 0.05, indicating the Fixed Effects Model (FEM) as the appropriate specification. Consequently, further testing using the Lagrange Multiplier (LM) test was deemed unnecessary.

Table 2. Chow Test Result

Effects Test	Statistic	d.f.	Prob.
Cross-section F	15.558923	(5, 135)	0.0000
Cross-section Chi-square	65.527586	5	0.0000

Based on the model selection results using the Chow test (Table 2.), the probability value of Chi-square was 0.000, indicating a value below the 0.05 significance level. This confirms the suitability of the Fixed Effects Model (FEM). Subsequently, the Hausman test was conducted to validate the Chow test results and ensure no model specification error in the selection process.

Table 3. Hausman Test Result

Test Summary	Chi-sq. Statistics	Chi-sq. d.f.	Prob.
Cross-section Random	77.616107	3	0.0000

The results of the Hausman test presented in Table 3 show a probability value of Chi-square of 0.000, which is below the 0.05 significance level. Therefore, based on both the Chow test and Hausman test results, it is conclusively determined that the Fixed Effects Model (FEM) is the appropriate specification for this study.

3.2. T-test, F-test, and R-Squared

Table 4. T-test and F-test Result

Variable	Coefficient	Prob.
C	714.2271	0.3324
CO2	-1768.582	0.0000
FOSC	0.447957	0.0000
RENC	3.102889	0.0000
F-statistics	564.2417	0.0000

The F-test results in Table 4. indicate that the three independent variables collectively have a significant impact on the dependent variable, as evidenced by an F-statistic of 564.2417 and a probability value of 0.00 (below the 0.05 significance level). Subsequent t-test results further confirm the individual significance of all three independent variables, with each showing a probability value of 0.00. The coefficient for the CO2 variable is -1768.582, indicating a negative relationship. This suggests that an increase in GDP per capita is associated with a decrease in CO2 emissions per capita. This finding implies that as populations achieve higher income levels, they tend to reduce their CO2 emissions, potentially by transitioning to energy sources with lower carbon footprints, such as renewable alternatives [19], [20]. This conclusion is reinforced by the renewable energy variable demonstrating a larger coefficient than the fossil fuel consumption variable, which generates substantially higher carbon emissions. Although both variables show positive values and contribute positively to GDP per capita, this indicates that economic output generation requires energy consumption from both renewable and non-renewable sources, including fossil fuels [21], [22]. The higher coefficient of renewable energy compared to non-renewable fuel signifies a growing awareness among populations in the six ASEAN countries to adopt renewable energy sources as their per capita income rises. Furthermore, the R-squared value of 92.36% from this analysis strongly confirms that 92.36% of the variation is explained by the variables in this study, while the remaining 7.64% is influenced by other factors outside the scope of this research.

However, interpreting this negative relationship between CO_2 and GDP per capita requires careful consideration. This finding aligns with the Environmental Kuznets Curve (EKC) hypothesis, suggesting that at a certain development stage, rising incomes drive demand for better environmental quality, leading to potential emission reductions. The larger coefficient for renewable energy (RENC) compared to fossil energy (FOSC) indicates that within the ASEAN context, each additional unit of renewable energy contributes more significantly to economic growth than an equivalent unit of fossil fuel energy [23]. This reflects a structural shift toward a greener and more efficient economy, where renewable energy not only plays a role in reducing emissions but also acts as a more productive catalyst of growth [24]. The high R-squared value (92.36%) reinforces the validity of the employed model, indicating that the proposed energy-environment-economy framework captures most of the variation in per capita GDP across the region.

3.3. Classical Assumption Test

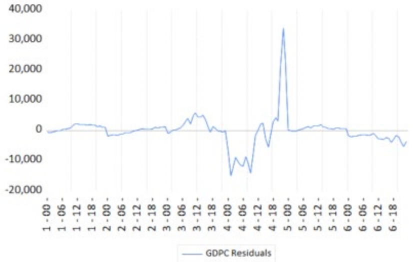

Fig. 2. Heteroscedastic Test with Residual

Based on the heteroskedasticity test results using the residual graph method (Fig 2.), several data points were observed to exceed the threshold values of 500 and -500, which represent the minimum residual requirement for heteroskedasticity testing. Therefore, this panel data does not meet the heteroskedasticity test requirements based on residual values [25].

Table 5. Multicollinearity Test Result

	CO2	FOSC	RENC
CO2	1.000	0.8531	0.0810
FOSC	0.8531	1.000	-0.1820
RENC	0.0810	-0.1820	1.000

Based on the multicollinearity test results in Table 5, a correlation value exceeding 0.85 was identified between CO2 and FOSC, specifically 0.8531. This indicates that the model does not satisfy the multicollinearity test requirements. Considering both the heteroskedasticity and multicollinearity test outcomes, it can be concluded that this regression model cannot be classified as a BLUE (Best Linear Unbiased Estimator) model. Nevertheless, the model remains applicable for examining the influence of independent variables on the dependent variable [26], [27].

3.4. Discussion

To facilitate the discussion in this study, the influence of the independent variables on the dependent variable for each country will be presented. This approach enables a more in-depth analysis and discussion. Table 6 will describe the influence of the independent variables on the dependent variable for each country.

Table 6. T-test, F-test, R-Squared Result for Every Country

Country	Variable	Coefficient	Prob.	R-squared	F-test
Indonesia	CO2	4271.333	0.000*	93.95%	103.66 (0.000*)
	FOSC	0.292	0.062**		
	RENC	-1.065	0.196***		
Malaysia	CO2	1832.75	0.071**	88.58%	51.76 (0.000*)
	FOSC	0.236	0.354***		
	RENC	1.005	0.004*		
Thailand	CO2	264.37	0.820***	96.30%	173.80 (0.000*)
	FOSC	0.403	0.043*		
	RENC	2.225	0.000*		
Singapore	CO2	1320.27	0.612***	91.75%	74.22 (0.000*)
	FOSC	0.537	0.000*		
	RENC	71.20	0.000*		

Philippines	CO2	13287.93	0.027*	79.76%	28.28 (0.000*)
	FOSC	-2.84	0.033*		
	RENC	-6.28	0.121***		
Vietnam	CO2	-446.05	0.192***	98.49%	437.43 (0.000*)
	FOSC	0.400	0.002*		
	RENC	0.771	0.000*		
***	Not significant at various levels				
**	Significant at the 0.1 level (10%)				
*	Significant at 0.05 level (5%)				

The data in the table 6. enables analysis of the relationship between the three independent variables and the dependent variable. The F-statistic probability values for all six countries (0.000) indicate that the independent variables collectively relate to the dependent variable, though some individual variables show insignificant effects in certain countries. The relationship between CO2 and GDP per capita demonstrates a positive influence, suggesting that increased CO2 emissions per capita correlate with higher GDP per capita across most countries. However, Vietnam presents a notable exception, showing a negative relationship where decreases in CO2 emissions correspond to increases in GDP. This finding aligns with the Vietnamese government's stated target of achieving net-zero emissions by 2050 [28].

The relationship between fossil fuel consumption and GDP per capita also shows a positive correlation. This finding indicates that higher fossil fuel usage correlates with increased GDP growth. However, the Philippines demonstrates a negative FOSC coefficient, suggesting that increased fossil energy use actually reduces GDP. This phenomenon results from the Philippines' heavy dependence on fossil fuels, making it particularly vulnerable to price volatility due to its substantial import volumes [29]. A positive relationship is also observed between renewable energy consumption and GDP per capita, with the exception of Indonesia and the Philippines which show negative coefficients. In both Indonesia and the Philippines, renewable energy remains relatively expensive and inaccessible to the general population [23], [30]. The high cost of renewable energy means that only wealthier segments of society can afford it, potentially reducing the disposable income of middle and lower-income households when they adopt renewable energy. In the Philippines, the income reduction effect from using renewable energy appears to be more pronounced compared to using fossil fuels [31]. This situation arises because renewable energy carries a higher price tag than fossil fuels, forcing consumers who choose it to bear a greater financial burden.

This study demonstrates substantial explanatory power across all selected countries. The results indicate that the model explains over 75% of GDP per capita variation in every country examined, with the remaining variance attributable to other factors. Among the studied nations, Vietnam shows the highest explanatory power with an R-squared of 98.49%, while the Philippines demonstrates the lowest, though still substantial, explanatory power at 79.76% [32], [33].

Overall, this study confirms that energy consumption (both renewable and fossil) and CO_2 emissions are significant determinants of GDP per capita in the ASEAN region. However, the most crucial key finding is the substantial heterogeneity in these relationships among countries. Indonesia and the Philippines remain locked in a paradigm where renewable energy is not yet economically competitive, meaning the transition could potentially suppress incomes in the short term [34], [35], [36], [37]. Conversely, Thailand, Vietnam, and Malaysia have reached a tipping point where renewable energy has begun contributing positively to growth, driven by consistent policy commitments and investments [38], [39], [40]. Meanwhile, Singapore, with its robust technological capital and strong fiscal capacity, has successfully transformed renewable energy into its most productive growth driver [41].

4. Conclusion

This study not only reinforces but also enriches the understanding of the Environmental Kuznets Curve (EKC) and the energy-growth-environment nexus in ASEAN. Empirical evidence reveals that the shape and phase of the EKC differ for each country, heavily influenced by policy readiness, technological capacity, and domestic economic conditions. The most urgent policy implication is the necessity for a differentiated approach. A *(one-size-fits-all)* strategy for energy transition in the region is destined to fail. Success instead lies in bespoke policies tailored to the specific context of each country—from addressing cost barriers in Indonesia and the Philippines, to accelerating investment in countries already on a positive trajectory, and supporting sustained innovation in front-runners like Singapore.

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