ENVIRONMENTAL KUZNETS CURVE THEORY ON ENVIRONMENTAL DEGRADATION IN ASEAN-5

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Abstract

The decline in environmental quality due to increasing greenhouse gas emissions is now a crucial challenge amidst the rapid industrialization of the Southeast Asian region. This study aims to empirically test the validity of the Environmental Kuznets Curve (EKC) hypothesis and analyze the effects of economic growth, energy consumption, population, and urbanization on CO_2 carbon dioxide emissions in the five founding countries of ASEAN (ASEAN-5), namely Indonesia, Malaysia, Thailand, the Philippines, and Singapore. Using secondary time series data from 2009 to 2023, the analysis was conducted using a panel data regression approach through the Fixed Effect Model (FEM) method corrected using White diagonal standard errors & covariance estimates to overcome heteroscedasticity and autocorrelation bias. The estimation results show that the economic growth variable (GDP) has a positive and significant effect, while the quadratic economic growth (GDP2) has a negative and significant effect on CO_2 emissions. This combination confirms the validity of the EKC hypothesis which forms the characteristics of an inverted U-Shape curve in the ASEAN-5 region. Through mathematical calculations, it was found that the turning point for the regional economy was at a nominal GDP per capita of 69,117.65 USD. In the control variable, total population (POP) was shown to have a positive and highly significant influence as the main driver of increasing carbon emissions. In contrast, the variables of energy consumption (energy use) and urbanization rate did not show a significant influence on CO_2 emissions at the regional aggregate level during the observation period. The results of this study indicate that most developing countries in the ASEAN-5 are still on the left side of the ecological curve (below the turning point threshold). Therefore, clean energy transition policy interventions, strict carbon exchange regulations, and eco-city spatial planning are needed to reduce emissions without sacrificing the rate of macroeconomic growth.

Keywords: CO_2 Emissions, Environmental Kuznets Curve (EKC), Fixed Effect Model, Economic Growth, Population, Turning Point

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INTRODUCTION

Environmental quality issues are now a global issue facing all countries. Various sources of pollution, such as industrial activity, motor vehicle emissions, and forest fires, periodically damage ecosystems. Therefore, in addition to driving economic growth, development focused on improving environmental quality is crucial (Todaro Michael P and Smith, 2005).

Environmental degradation, measured through carbon (CO_2) emissions, can contribute to economic development through energy consumption that supports production processes (Acheampong, 2018; Menyah & Wolde-Rufael, 2010). Furthermore, economic development indicators are often considered inaccurate because they ignore important elements such as public aspirations, technological development, and geopolitical risks, which can impact the reliability of government policies (Bradbury & Matt, 2024).

CO_2 emissions are widely known to be caused by human activity, one of which is economic development. This supports the reasonable EKC speculation that during the initial period of economic development, a nation will experience a natural decline. This is because countries will focus more on expanding their production frontiers and ignore the impact on the climate. This continuous process of creation causes ecological degradation through pollution of land, air, and water (Utami & Khoirudin, 2021).

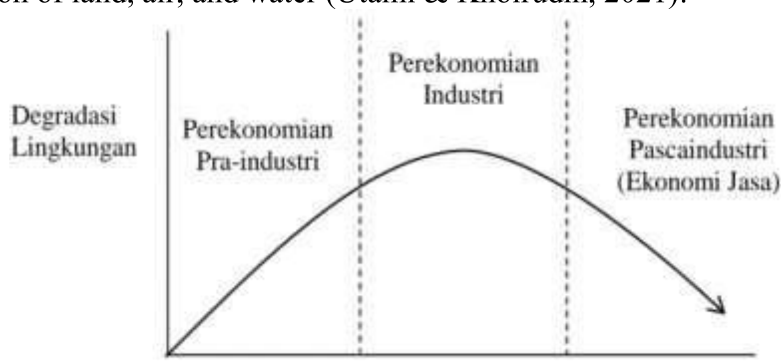

Figure 1.
Environmental Kuznets Curve (EKC) image
Source: Shaharir & Alinor, 2013

Economic development in a region can accelerate urbanization and increase energy consumption. The relationship between urbanization, economic growth, and $CO_2$2 emissions has been strongly demonstrated in several studies (Aguir Bargaoui, Liouane, & Nouri, 2014; Lin, Sun, Marinova, & Zhao, 2017; Lin, Zhao, & Marinova, 2009; Liu, Yan, & Zhou, 2016; Wang, Zhao, Zheng, & Hu, 2017; Zhou & Liu, 2016). Therefore, urbanization is believed to drive greater environmental degradation. Urban communities can alter the environment through the consumption of energy, water, food, and land. In turn, increasingly polluted urban environments impact the health and quality of life of urban residents.

Furthermore, a study by Aguir Bargaoui et al. (2014), Sadorsky (2014), Heryadi and Hartono (2016), and Wang, Zhao, Zheng, and Hu (2017) proved that urbanization, economic growth, and energy consumption have a significant influence on CO_2 emissions. On the other hand, a study conducted by Agung et al. (2012) and Zhou and Liu (2016) showed that urbanization does not affect energy consumption and CO_2 emissions. Sebri and Ben-salha (2014), Chang et al. (2017), Pao and Tsai (2010), and Zakarya et al. (2015) proved that there is a causal relationship between economic growth and energy consumption. Liu, Yan, and Zhou (2016) found that urbanization, economic growth, and CO_2 emissions can be integrated; other findings also prove that there is a bidirectional causality between urbanization, economic growth, and CO_2 emissions in China. CO_2wan et al. (2014) found evidence that economic growth and CO_2 emissions have a bidirectional causal relationship. Furthermore, we have conducted related studies showing that human capital, energy consumption, and economic growth all contribute to CO_2 emissions in the short term (Bashir et al., 2019).

The empirical and theoretical evidence above highlights the urgency of examining this phenomenon within the Southeast Asian region, particularly within the ASEAN-5 group of countries, including Indonesia, Malaysia, Thailand, the Philippines, and Singapore. As the five largest economic powers and pioneers of integration in Southeast Asia, the ASEAN-5 bloc is undergoing rapid structural transformation. On the one hand, industrial acceleration, population agglomeration, and a surge of urbanization in megacities like Jakarta, Kuala Lumpur, Bangkok, and Manila have significantly boosted regional gross domestic product. On the other hand, this economic leap has come at the cost of serious environmental degradation, making this bloc one of the largest contributors to carbon emissions in Southeast Asia.

This situation is crucial. The disparity in welfare levels and technological orientation among ASEAN-5 member countries is stark. Singapore has transformed into a high-income developed country based on a circular economy and low-emission technologies. In contrast, Indonesia, Malaysia, Thailand, and the Philippines remain in a development phase heavily reliant on fossil fuels and large-scale natural resource exploitation. This paradigm difference raises uncertainty about whether aggregate economic growth in the ASEAN-5 can truly lead the region toward a turning point in environmental improvement, as exemplified by the EKC curve hypothesis, or whether the industrialization trap will continue to permanently exacerbate emissions as population and energy consumption grow. To address this question, robust and consistent empirical data are needed. Testing environmental theories can no longer be based solely on theoretical assumptions but must be tested using real, long-term indicators. The availability of measurable panel data from the ASEAN-5 group—such as annual carbon dioxide emissions, fluctuations in gross domestic product (GDP), per capita energy consumption, total demographic dynamics, and the percentage of urban population migration—is a crucial instrument. Through the reconstruction of this quantitative empirical data, this thesis is expected to map the real ecological position of each country in the development curve and formulate adaptive green economy transition policy directions for the future sustainability of the Southeast Asian region.

REVIEW OF LITERATURE

The relationship between urbanization, economic growth, and environmental degradation has been strongly demonstrated in various previous studies (Lin et al., 2009; Aguir Bargaoui et al., 2014; Zhou & Liu, 2016; Liu et al., 2016; Wang et al., 2017).

Empirical evidence regarding the relationship between these three aspects is confirmed by Liu et al. (2016) and Saidi and Mbarek (2017), who found that urbanization, economic growth, and technological development have a long-term impact on increasing CO_2 emissions in developing countries. Increased economic activity in urban areas, accompanied by a surge in energy consumption, is a key driving factor. This phenomenon is driven by the higher economic needs in urban areas compared to rural areas (Ding et al., 2017).

More in-depth research is rapidly developing. Lin et al. (2009) tested the existence of the Environmental Kuznets Curve (EKC) in developed countries using the STIRPAT equation model approach. Their research findings demonstrate that population factors have the greatest potential environmental impact, followed by urbanization rate, industrialization rate, GDP per capita, and energy intensity. Furthermore, Martínez-Zarzoso and Maruotti (2011) analyzed the impact of urbanization on CO_2 emissions in developing countries during the period 1975–2003. Their findings suggest that the relationship between urbanization and CO_2 emissions can form an inverted U-shaped curve. However, in some regions with low levels of development, the urbanization elasticity is positive, meaning that early urbanization actually triggers higher environmental impacts. Conversely, in several developed countries, increasing urbanization was found to no longer contribute to increased CO_2 emissions.

In the Southeast Asian context, Agung et al. (2012) investigated the effect of urbanization on energy consumption and CO_2 emissions in Indonesia using the STIRPAT model approach with panel data. The results of this study demonstrated that urbanization significantly impacts fuel consumption and total energy consumption, but not CO_2 emissions. Conversely, economic and population growth have been shown to significantly influence CO_2 emissions in Indonesia. Consistent with this, Aguir Bargaoui et al. (2014) assessed the environmental impacts of economic growth, population growth, urbanization, energy intensity, and Kyoto Protocol obligations on carbon dioxide emissions using the STIRPAT model. The study found that the aggregate environmental impact was largely dominated by economic growth through per capita income.

Sadorsky (2014) used a panel data regression model to examine the impact of urbanization, per capita income, and energy efficiency. Statistically, per capita income and energy intensity were shown to have significant and positive effects on CO_2 emissions, while the coefficient for the urbanization variable was positive but insignificant. This finding regarding the dominance of income was also confirmed by Zhou and Liu (2016) in China, where income was the primary driver of increasing CO_2 emissions. However, in contrast to Sadorsky, Zhou and Liu (2016) found that urbanization in China significantly increased energy consumption and CO_2 emissions.

Liu et al. (2016) investigated the dynamic relationship between urbanization, economic growth, and carbon dioxide emissions using the Panel CO_2integration and Vector Error CO_2rection Model (VECM) approaches. This study found a bidirectional causal relationship between urbanization, economic growth, and long-term CO_2 emissions. Furthermore, their in-depth investigation showed that the relationship between CO_2 emissions and economic growth in China forms an N-shaped curve, meaning the classic inverted-U-shaped EKC hypothesis is not supported.

RESEARCH METHOD

This study uses panel data regression analysis to examine the influence of several independent variables on carbon dioxide emissions in the five founding members of ASEAN (ASEAN-5). This analysis utilizes 75 balanced panel observations covering the period 2009 to 2023. The independent variables tested include economic growth, squared economic growth, energy consumption (Energy Use), population, and urbanization rate.

The advantages of using a panel data regression model include: (i) larger data volume because it encompasses both time and space; (ii) it can avoid bias in estimation; (iii) it can explain variable behavior more dynamically; and (iv) it can avoid multicollinearity, so the panel data model estimation method does not use Ordinary Least Squares (OLS) and does not require testing for deviations from classical assumptions.

The basic model used in this study is as follows:

$$\mathbf{CO_{2it} = \beta_0 + \beta_1 GDP_{it} + \beta_2 GDP^2_{it} + \beta_3 POP_{it} + \beta_4 EC_{it} \beta_4 + URB_{it} \beta_5 + u_{it}}$$

Table 1.
Research Data Sources

Data Type	Symbol	Description	Year	Data Source
Carbon Emissions (Metric Tons per Capita)	CO_2	CO_2 (carbon dioxide) emissions refer to emissions generated from the combustion of fossil fuels and cement manufacturing. This measure also includes carbon dioxide produced during the consumption of solid, liquid, and gaseous fuels, as well as gas flaring activities.	2009–2023	World Bank, Our World in Data
Gross Domestic Product (USD per Capita)	GDP	GDP per capita is the total value added by all producers plus taxes on products (minus subsidies) not included in the valuation of output. It is calculated by dividing a country's Gross Domestic Product (GDP) by its total population.	2009–2023	World Bank
Squared Gross Domestic Product (USD^2 per Capita)	GDP^2	Represents the squared value of GDP. This variable is used to test the existence of the Environmental Kuznets Curve (EKC) hypothesis within the selected group of countries.	2009–2023	Processed Data
Population (Persons)	POP	The total number of people residing in a specific area at a given point in time.	2009–2023	World Bank
Energy Consumption (Kg of Oil Equivalent per Capita)	EC	Energy consumption refers to the level of primary energy use per capita before final fuel consumption. It is measured as domestic production plus imports and stock changes, minus exports and fuels supplied to ships and aircraft engaged in international transportation.	2009–2023	World Bank
Urbanization	URB	The proportion or percentage of the population living in urban areas relative to the total population of a country. This variable serves as a proxy for agglomeration processes and demographic shifts.	2009–2023	World Bank

RESULTS AND DISCUSSION

Panel data regression analysis was conducted using the Fixed Effect Model (FEM) approach, which was selected as the best model based on a series of model tests using the Chow and Hausman tests. To anticipate bias due to autocorrelation and heteroscedasticity in cross-country data, this model was estimated using the White diagonal standard errors and covariance (d.f. corrected) method.

Panel Data Regression Estimation Results (Fixed Effect Model)

Table 2.
Panel Data Regression Estimation Results (Fixed Effect Model)

Variable	Coefficient	Std. Error	t-Statistic	Prob.	Remark
C (Constant)	1.250796	0.370842	3.372851	0.0013	Significant
GDP	0.000141	0.000049	2.879225	0.0054	Significant (α = 5%)
GDP^2	-1.02E-09	2.96E-10	-3.460631	0.0010	Significant (α = 1%)
EC	7.86E-06	1.51E-05	0.519882	0.6049	Not Significant
POP	1.78E-08	2.97E-09	5.998149	0.0000	Significant (α = 1%)
URB	-1.12E-05	0.000061	-0.184994	0.8538	Not Significant

Source: Processed Data (EViews), 2026.

Simultaneous hypothesis testing using the F-test indicates that all independent variables simultaneously have a significant influence on CO_2 emissions in the ASEAN-5, as indicated by an F-statistic of 1553.032 with a Prob(F-statistic) of 0.000000. The coefficient of determination (Adjusted R-squared) obtained from this FEM model is 0.994730. This value indicates that 99.47% of the variation in CO_2 emissions in the ASEAN-5 region can be explained by the independent variables within the model, while the remaining 0.53% is explained by factors outside the research model.

Analysis of the Influence of Driving Variables on the EKC Curve (GDP and GDP2)

Based on the final estimation results, the economic growth (GDP) variable exhibits a positive and significant effect on CO_2 emissions, with a coefficient value of 0.000141 and a probability value of 0.0054 (below $\alpha = 0.05$). Conversely, the quadratic economic growth (GDP2) variable exhibits a negative and significant effect on CO_2 emissions, with a coefficient value of -1.02E-09 and a probability value of 0.0010.

This combination of results empirically proves the validity of the Environmental Kuznets Curve (EKC) Hypothesis in the ASEAN-5 region, which forms an inverted U-shaped curve. In the early stages of economic development, increasing per capita income will drive up CO_2 emissions due to intensive industrialization activities that compromise environmental quality. However, after passing a certain turning point in prosperity, future GDP increases will mitigate emissions as countries adopt clean technologies, shift their economic structure toward the service sector, and tighten environmental regulations. This finding aligns with the basic environmental economic theory of Grossman & Krueger (1995), which states that environmental degradation will eventually decline once the economy passes a certain welfare threshold.

Turning Point Analysis of the EKC Curve

To determine when CO_2 emissions peak before they eventually decline, a mathematical calculation of the Turning Point value is performed. After determining a country's EKC, the next step is to calculate the Turning Point (TP) using the following formula (Emalia et al., 2020; Bashir et al., 2021; Faizah et al., 2021; Vikia et al., 2023).

Turning point= $-\frac{\beta_1}{2\beta_2}$

Where $\beta_1$is per capita income; and $\beta_2$is per capita income squared.

The ASEAN-5 economic turning point was calculated at US$69,117.65.

This US$69,117.65 figure reflects the theoretical nominal GDP per capita threshold that must be passed for economic growth in the region to begin to have a positive impact on real emissions reductions. From a development economics perspective, this high turning point indicates a contrasting structural gap among ASEAN-5 countries during the 2009–2023 period:

1. Singapore is the only sample country that has moved to the right side of the curve (beyond the turning point), where its high economic growth has been accompanied by mature decarbonization policies and low-emission technologies.
2. Indonesia, Malaysia, Thailand, and the Philippines are currently still on the left side of the curve (not yet reaching the turning point). Because the real GDP per capita of these four countries remains below the US$69,117 threshold, their economic activity is still in a phase of industrial expansion that exploits fossil fuels. Consequently, any efforts to spur economic growth in these countries will still be accompanied by increased CO_2 emissions. This phenomenon emphasizes that developing countries in ASEAN require technology transfer and large-scale green investment to accelerate the achievement of peak emissions without having to wait for natural GDP growth.

Analysis of the Effect of Control Variables (Population, Energy, and Urbanization)

The effect of the total population (POP) variable on CO_2 emissions shows a positive and highly significant result, with a coefficient value of 1.78E-08 and a probability of 0.0000. This result indicates that population growth in the ASEAN-5 directly drives increased carbon dioxide emissions. Based on the STIRPAT theoretical framework, the population explosion increases ecological pressure due to increased domestic needs, consumption of goods, and demand for daily mobility. Dense residential and transportation sectors are major contributors to emissions. This finding aligns with research by R Al Latifa (2022), which states that population growth is closely correlated with the expansion of physical development activities, which triggers increased greenhouse gas emissions.

Meanwhile, the energy consumption variable (energy use) has a positive coefficient of 7.86E-06, but a probability value of 0.6049 (much greater than 0.05). These statistical results indicate that energy consumption does not significantly influence CO_2 emissions in the ASEAN-5 aggregate during the observation period. This indicates contrasting variations in energy governance across the sample countries. For example, Singapore, with its high per capita energy use, has been shown to be able to reduce direct emissions through a strict efficiency system, resulting in non-linear dynamics of energy consumption volume dictating fluctuations in emissions at the regional level.

Finally, the urbanization variable (urbanization) shows a negative coefficient of -1.12E-05 with a probability value of 0.8538. Because the probability value is far above 0.05, urbanization is deemed to have no significant effect on CO_2 emissions in the ASEAN-5 during the 2009–2023 period. The phenomenon of rural-to-urban population migration in this region is not a dominant factor in changing carbon emission fluctuations at the macro level. This is because the urbanization process in several major ASEAN cities has now //been balanced by smart city initiatives and the expansion of electric-based mass transportation (such as MRT and LRT), which neutralizes the negative impact of urban population concentration on air quality.

CONCLUSION

Based on the results of a quantitative analysis using the Fixed Effect Model (FEM) in the ASEAN-5 region for the period 2009–2023, this study successfully drew several crucial conclusions, as follows:

1. Validity of the EKC Hypothesis: The Environmental Kuznets Curve (EKC) hypothesis has been empirically proven to be valid in the ASEAN-5 region. This is indicated by the significantly positive GDP coefficient ($\beta1$) and the significantly negative GDP^2 coefficient ($\beta2$), confirming the existence of an inverted U-shaped relationship between economic growth and CO_2 emissions.
2. Country Position at the Turning Point: Mathematical estimates indicate a contrasting ecological imbalance across the region. Singapore is the only country that has successfully passed the turning point and is on the right side of the curve, where its economic growth is now linear with emissions reductions. In contrast, the other four countries (Indonesia, Malaysia, Thailand, and the Philippines) remain on the left side of the curve, indicating that their economic growth continues to come at the expense of environmental quality.
3. Impact of Control Variables: The population size (POP) variable was shown to have a positive and significant effect on increasing CO_2 emissions due to aggregate household consumption demands. Meanwhile, the energy consumption (EC) and urbanization rate (URB) variables did not show a significant regional effect. This is due to the offsetting effect between high-tech efficiency in Singapore and conventional energy consumption patterns in four other developing countries.

Policy Implications

Referring to the above conclusions, several adaptive and strategic policy recommendations are proposed for relevant authorities:

1. Accelerating the Green Energy Transition: For authorities in Indonesia, Malaysia, Thailand, and the Philippines, strict regulations must be immediately directed at decarbonizing the industrial sector. The government needs to provide fiscal incentives such as tax holidays for renewable energy investments (solar, hydro, geothermal) to accelerate the achievement of the turning point without sacrificing GDP growth.
2. Cross-Border Technology Adoption (Technology Transfer): Strengthening bilateral and multilateral cooperation within the ASEAN-5 is needed. Singapore, as a regional pioneer in the circular economy and low-emission smart cities, can be a strategic partner in green technology transfer to help the other four member states mitigate emissions in the urban and manufacturing sectors.
3. Demographic Impact Management: Given the significant impact population size has on environmental degradation, population growth policies must be balanced with education on eco-friendly lifestyles and the provision of electric-based public transportation infrastructure to reduce the personal carbon footprint in densely populated areas.

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