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Dynamics of urbanization, industry, energy, and emissions on economic growth in middle-income ASEAN countries

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Abstract

This study analyzes the asymmetric influence of urbanization, industrial value added, electricity consumption, renewable energy use, and CO_2 emissions on economic growth in middle-income ASEAN countries over the period 1990–2023. Using a fixed-effects panel quantile regression approach, the results indicate that urbanization, electricity consumption, renewable energy utilization, and CO_2 emissions exhibit positive and statistically significant effects on economic growth, whereas industrial value added shows no meaningful contribution across quantiles. The effect of urbanization is more pronounced at lower quantiles, underscoring its strategic importance during earlier stages of economic development. These findings provide empirical insights for policymakers in formulating strategies related to urban management, energy diversification, and emissions mitigation to support sustainable economic performance.

Keywords

Urbanization, Industrial value added, Energy consumption, CO_2 emissions, Economic growth

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Introduction

Asia has strengthened its position as one of the world's most dynamic engines of growth, driven by rapid urbanization, industrial expansion, intensifying energy demand, and rising environmental pressures [17]. These structural shifts underscore the need for sustainable development strategies, including a broader transition toward renewable energy as a response to economic–environmental challenges [3]. Within this regional landscape, ASEAN emerges as a fast-growing bloc facing similar pressures related to structural change and sustainability.

ASEAN economies share broadly comparable development paths marked by demographic expansion, industrial upgrading, and increasing urban concentration. However, these achievements coexist with the challenge of maintaining economic progress while managing environmental degradation that threatens long-term sustainability [6]. Most member states also fall within the middle-income category [16], sharing common concerns regarding industrial restructuring, energy security, and emission mitigation [5].

Neo-classical growth theory highlights the role of urbanization and industrialization in driving capital accumulation, productivity, and technological progress, supported by modern energy systems particularly electricity. Yet reliance on fossil-based energy simultaneously raises CO_2 emissions, creating tension between growth and environmental quality [20].

Although extensive studies have examined the relationships among urbanization, industrial activity, energy use, and environmental outcomes, gaps remain particularly regarding how these variables influence economic growth asymmetrically across development levels within middle-income ASEAN countries. Much of the existing literature relies on mean-based estimators that obscure distributional heterogeneity.

This study addresses these gaps by applying fixed-effects panel quantile regression to evaluate how these variables shape economic growth across multiple conditional distributions, providing an evidence-based understanding of the structural forces influencing economic performance in middle-income ASEAN countries from 1990 to 2023.

Method

The quantile regression equation is expressed as follows:

$$Q_{yi}(\tau|x_i) = x_i^{\tau}\,\beta_{\tau} \quad (1)$$

The general form of the quantile regression equation using a fixed-effects model is:

$$Q_{yit}(\tau_k|\alpha_i, x_{it}) = \alpha_i + x'_{it}\beta(\tau_k) \quad (2)$$

The objective function for the fixed-effects quantile regression estimator is:

$$\min_{(\alpha,\beta)} \sum_{k=1}^{K}\sum_{t=1}^{T}\sum_{i=1}^{N} w_k\,\rho_{\tau_k}\left(y_{it} - \alpha_i - x_{it}^{T}\beta(\tau_k)\right) + \lambda \sum_{i}^{N}|\alpha_i| \quad (3)$$

The equation states that N indicates the number of countries that are the objects of the study, while K represents the number of observations used in the analysis. T refers to the quantiles analyzed in the model, while X describes the factors or explanatory variables that influence the outcome variable. Furthermore, ρ_(τ_k) is a check function that represents the actual value at a certain quantile, W_k is the weight given to each quantile or observation, and λ is a penalty parameter that plays a role in controlling and influencing individual effects in the model.

The model used in this study is formulated as follows:

$$Q_{y_{it}}(\tau|\alpha_i, \varepsilon_t, x_{it}) = \alpha_i + \varepsilon_t + \beta_{1_\tau}UPG_{it} + \beta_{2_\tau}IVA_{it} + \beta_{3_\tau}LOGEC_{it} + \beta_{4_\tau}REC_{it} + \beta_{5_\tau}LOGCO2_{it} \quad (4)$$

The equation states that Q_(y_it) represents the quantile function of the dependent variable y for country i. The parameter α_i indicates the country fixed effect, which reflects the unique characteristics of each country, while ε_t describes the time effect, which represents the general trend affecting all countries. The LOGGDP variable is used as a proxy for economic growth, UPG reflects the level of urbanization as measured by the urban population, IVA represents industrial value added, LOGEC indicates electricity consumption, REC describes renewable energy consumption, and LOGCO2 represents CO_2 emissions. Furthermore, β_1τ, β_2τ, β_3τ, β_4τ, and β_5τ are regression coefficients at each quantile that indicate the magnitude of the influence of each independent variable on the dependent variable at a certain quantile level.

Results and discussion

Descriptive statistics

The estimation results from the descriptive statistics Table 1 show that the mean value is higher than the standard deviation for the LOGGDP, UPG, EC, REC, and CO_2 variables, which indicates that the data is well distributed. However, for the IVA variable, the data looks more dispersed.

Table 1. Descriptive statistics

	LOGGDP	UPG	IVA	LOGEC	REC	CO_2
Mean	11.00863	41.23593	7.213019	1.423950	42.17788	4.735448
Median	11.18361	35.91900	6.978700	1.687796	39.30000	4.935331
Maximum	12.02091	82.55362	36.68064	2.432971	85.80000	5.781964
Minimum	9.616754	17.31100	-13.95133	-0.841638	2.000000	2.999048
Std.Dev.	0.623643	18.52514	7.223399	0.770531	24.68692	0.740702
Probability	0.000050	0.000000	0.000000	0.000001	0.004357	0.000006
Obs	217	217	217	217	217	217

Heteroscedasticity test

The heteroscedasticity test detects whether the error variance in the regression model is not constant Table 2. This study uses the Glejser method, where if the p-value < α (0.05), the model has heteroscedasticity, while if the p-value > α (0.05), the model is free from these problems [28].

Table 2. Heteroscedasticity test

Variable	Coefficient	Std. Error	t-Statistic	Prob
C	-0.253527	0.110962	-2.284809	0.0234
UPG	-4.43E-05	0.000623	-0.071095	0.9434
IVA	0.000307	0.000357	0.858056	0.3919
LOGEC	-0.031514	0.018336	-1.718743	0.0872
REC	0.000526	0.000492	1.068866	0.2864
$LOGCO_2$	0.066795	0.023345	2.861178	0.0047

Based on the results of the heteroscedasticity test above, it shows that the variables UPG, IVA, LOGEC, and REC are not significant, while LOGCO2 has a significant effect.

Normality test

In this study, normality testing was carried out using histograms and the Jarque-Bera (JB) test. According to [28], residuals are said to be normally distributed if the probability value of the J-B test is greater than the significance level (α = 0.05). In accordance with the normality test results in Table 3, the normality test using the Jarque–Bera method indicates that the residuals are not normally distributed. However, in panel data with large observations, the normality assumption is not crucial [9].

Table 3. Normality test

Normality Test	
Jarque-Bera	40.05457
Probability	0.000000

Outlier test

The outlier test is conducted to detect data observations with extreme values or significant deviations from the overall data pattern Figure 1. The presence of outliers can affect the estimation of regression parameters, reduce model efficiency, and cause bias in the analysis results [29].

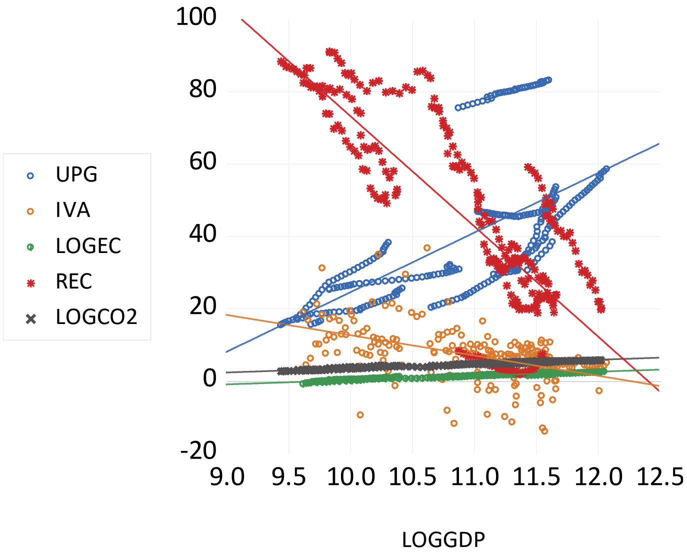

Figure 1. Outlier test

Scatter plot analysis shows a mixed pattern between LOGGDP and the study variables. REC has a negative relationship, UPG is positive with two groups of data, and IVA fluctuates. Meanwhile, LOGEC and LOGCO2 are stable without significant outliers, while REC, UPG, and IVA have outliers.

Quantile regression estimation test

The estimation results show that urbanization, electricity consumption, renewable energy consumption, and CO_2 emissions have a positive and significant effect on economic growth, with coefficient values of 0.002630, 0.310892, 0.006363, and 0.623880, respectively. Value added in the industrial sector, on the other hand, has a coefficient of -0.000112 (p-value = 0.9241), indicating a negative and insignificant effect. Except for value added in the industrial sector, the other effects are significant at α = 5 percent Table 4.

Table 4. Quantile regression estimation test

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	7.244113	0.136202	53.18635	0.0000
UPG	0.002630	0.000513	5.131000	0.0000
IVA	-0.000112	0.001175	-0.095389	0.9241
LOGEC	0.310892	0.038837	8.004965	0.0000
REC	0.006363	0.000564	11.27628	0.0000
$LOGCO_2$	0.623880	0.037324	16.71527	0.0000
Pseudo R-squared	0.857884		Mean dependent var	11.00863
Adjusted R-squared	0.854517		S.D. dependent var	0.623643
S.E. of regression	0.102492		Objective	7.673300
Quantile dependent var	11.18361		Restr. objective	53.99335
Sparsity	0.177155		Quasi-LR statistic	2091.725
Prob (Quasi-LR stat)	0.000000			

Fixed effects panel quantile regression

The quantile regression results show that there are variations in coefficient values by quantile for various variables, with most variables showing a significant positive impact on economic growth. However, value added in the industrial sector shows an insignificant negative impact Table 5.

Table 5. Fixed effects panel quantile regression

Variable		Quantile (ϴ)								
		0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
UPG	Coef	0.007677	0.006072	0.006043	0.003406	0.00263	0.003041	0.003326	0.002702	-0.000203
	Prob	0.0067	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0021	0.9891
IVA	Coef	-0.00249	-0.00056	-0.00029	-0.00037	-0.00011	-0.00017	-7.63E-06	-0.00085	0.000302
	Prob	0.1985	0.7214	0.7776	0.7655	0.9241	0.8887	0.9941	0.5029	0.8977
LOGEC	Coef	0.498524	0.333065	0.311989	0.31461	0.310892	0.314607	0.353316	0.404294	0.456564
	Prob	0.0980	0.0591	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0451
REC	Coef	0.011086	0.009534	0.009305	0.006894	0.006363	0.007208	0.007694	0.007420	0.003384
	Prob	0.0052	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.3040
$LOGCO_2$	Coef	0.556170	0.628934	0.617078	0.618182	0.623880	0.635976	0.597956	0.551509	0.474261
	Prob	0.0248	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0003
C	Coef	6.763427	6.842488	6.957810	7.194025	7.244113	7.146348	7.254782	7.468439	8.111108
	Prob	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Urbanization contributes positively to economic growth with a significance level below 0.05, with the impact more pronounced in regions with lower urbanization levels. This finding is consistent with [10] and [36], who state that urbanization improves urban efficiency and productivity and supports economic growth through effective infrastructure planning. However, without proper management, the positive impact of urbanization may weaken in the long run [1].

In middle-income ASEAN countries, value added in the industrial sector does not show a significant relationship with economic growth, consistent with [30], who observed that the industrial sector in developing countries is shifting towards a more dominant service sector. Electricity consumption is shown to have a significant impact on economic growth, especially in quantiles 0.3 to 0.8, emphasizing the role of electricity in improving productivity, economic efficiency, and quality of life [12][21].

Renewable energy consumption has a significant effect on economic growth in most quantiles, highlighting the importance of renewable energy policies in promoting sustainable economic growth and reducing dependence on fossil energy [1][32]. CO_2 emissions also have a significant positive effect on economic growth, supporting the

Environmental Kuznets Curve (EKC) concept that emissions may decrease with the adoption of clean technologies and sustainable energy policies [15][22].

Slope fixed effect panel quantile

At each quantile, the urbanization coefficient (UPG) falls from θ = 0.1 to θ = 0.8 to negative at θ = 0.9. According to this, urbanization benefits those with lower economic growth rates more than those with higher economic growth rates. However, as economic growth increases, the urbanization effect decreases and even turns negative at the highest quantile Figure 2.

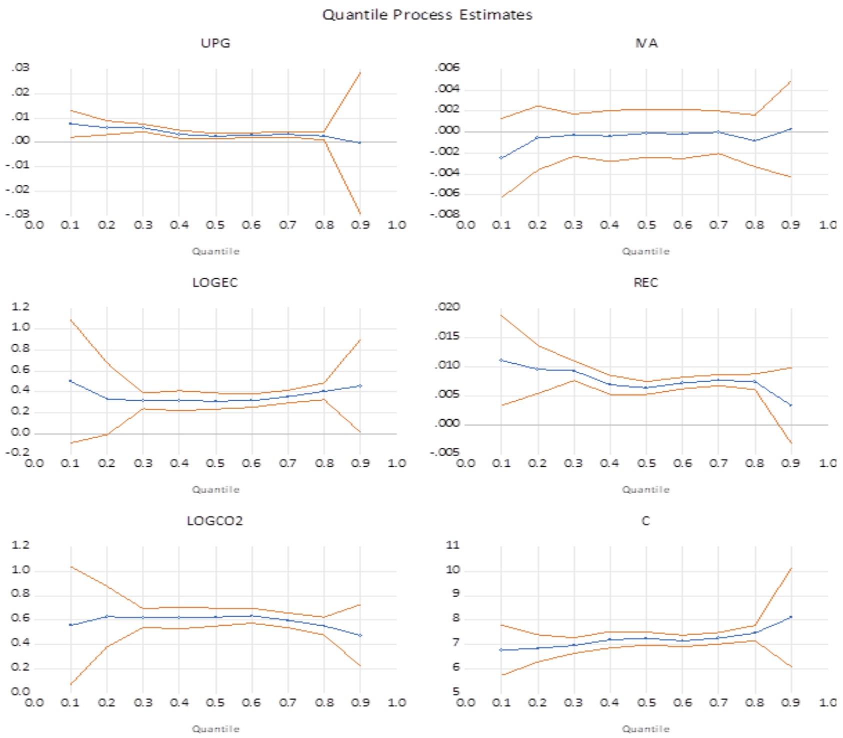

Figure 2. Slope Fixed Effect Panel Quantile

This finding supports Lewis' theory that rural–urban migration contributes to economic development by reallocating labor from agriculture to industry. However, at high levels of urbanization, pressure on infrastructure and public services may weaken the positive impact of urbanization on economic growth [24]. The coefficient of industrial sector value added (IVA) changes from negative to positive in each quantile, increasing gradually from θ = 0.1 and continuing to be positive until θ = 0.9. This finding is consistent with the Neo-Classical Growth Theory that emphasizes the role of the industrial sector in driving economic growth through capital investment, productivity improvement, and efficiency.

The coefficient of electricity consumption (LOGEC) is positive but volatile, while the coefficient of renewable energy consumption (REC) is also positive but decreases across quantiles. According to Neo-Classical Growth Theory, energy is a crucial factor of production in improving productivity and efficiency, although excessive reliance on electricity from fossil sources can hamper growth due to environmental impacts [35].

The decreasing coefficient of renewable energy consumption can be explained through the Environmental Kuznets Curve (EKC) Theory, which reveals that its contribution to growth tends to decline at very high levels of consumption [33]. The CO_2 emissions coefficient ($LOGCO_2$) is positive but fluctuating, consistent with the Environmental Kuznets Curve (EKC) theory, where emissions increase in the early phase of growth but decline after a certain tipping point due to sustainable policies and environmental awareness [7]. The findings suggest that at very high emission levels, the contribution of CO_2 emissions to economic growth diminishes [35].

Conclusion

This study investigates how urbanization, industrial value added, electricity consumption, renewable energy utilization, and CO_2 emissions shape economic growth across eight middle-income ASEAN economies from 1990 to 2023 using a quantile regression framework. The findings demonstrate that the contribution of urbanization to economic expansion is strongest in countries positioned at the lower quantiles of the growth distribution, while this influence gradually diminishes as countries move toward higher development levels.

The analysis further reveals that industrial value added does not significantly stimulate growth across quantiles. In contrast, electricity consumption consistently enhances economic performance, and renewable energy also demonstrates a significant positive effect. The positive association between CO_2 emissions and economic growth aligns with the Environmental Kuznets Curve. These findings emphasize the need for policies that integrate energy transition strategies, green industrialization, and urban planning reforms to sustain growth while mitigating environmental degradation.

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