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Economic Growth, Energy Consumption, Urbanization, and Ecological Footprint in ASEAN: A Panel Analysis

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This study examines how economic growth, energy consumption, and urbanization are associated with the per capita ecological footprint in eight Association of Southeast Asian Nations (ASEAN) members during 2010–2022, where ecological pressure varies sharply and earlier evidence is inconsistent. An observational associative design was applied to a balanced panel of 104 country-year observations from the World Bank and the Global Footprint Network. The Chow and Hausman tests selected the Fixed Effect Model, followed by diagnostic and robustness checks. In the main model, economic growth (annual GDP per capita growth, %), energy consumption (kilograms of oil equivalent per capita), and urbanization (urban population, % of total) were each positively associated with the ecological footprint (global hectares, gha, per capita) at the 5% level and jointly (Wald $F = 16.27$, $p < 0.001$). Holding the other variables constant, a one-percentage-point higher growth rate, a one-percentage-point higher urban share, and an additional 100 kilograms of oil equivalent per capita were associated with 0.012, 0.014, and 0.069 gha per capita more footprint, respectively. These are statistical associations, not causal effects. Energy consumption was the most robust association across alternative specifications, whereas the significance of growth and urbanization depended on the standard-error estimator. The results are consistent with development still being accompanied by rising ecological pressure while energy remains fossil-fuel dependent, although the design cannot identify this mechanism. Improving energy efficiency and accelerating the shift to renewable energy are the best-supported policy priorities, with sustainable urban planning as a supporting measure.

Keywords: ASEAN, Ecological Footprint, Economic Growth, Energy Consumption, Urbanization.

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INTRODUCTION

Economic development brings growing pressure on the natural environment, as industrialization, rising energy use, and expanding cities raise the demand for natural resources (Todaro and Smith, 2012). This condition reflects the close relationship between economic activities and environmental sustainability, particularly as population growth and consumption patterns continue to increase resource demands. The ecological footprint captures this pressure as the area of productive land and water needed to supply the resources people consume and absorb the carbon they emit, set against the capacity of ecosystems to regenerate (Wackernagel and Galli, 2007). Through this concept, the balance between human resource consumption and the environment's ability to recover can be assessed. Global demand now exceeds that capacity, at the equivalent of more than 1.7 Earths (Global Footprint Network, 2025).

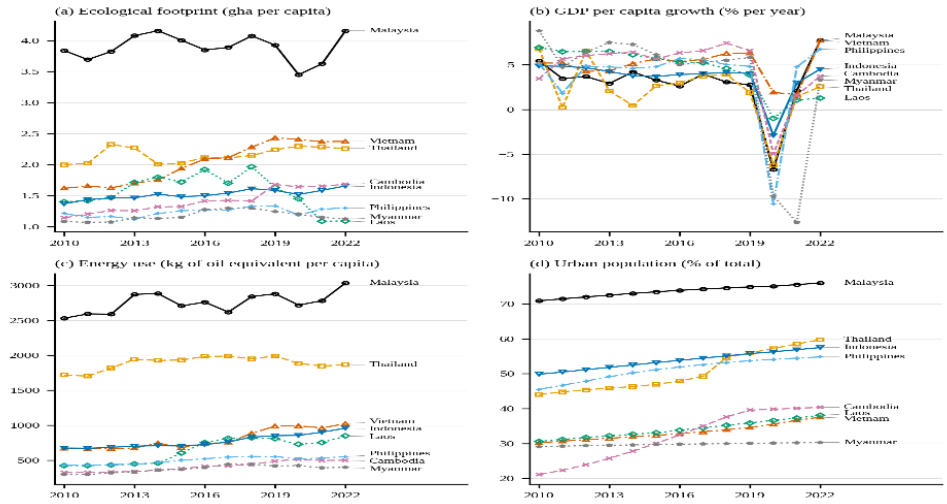


Figure 1. *Ecological footprint and candidate drivers in eight ASEAN countries, 2010–2022: (a) ecological footprint; (b) annual growth in gross domestic product (GDP) per capita; (c) energy use per capita; (d) urban population share.*

Southeast Asia shows how unevenly this pressure is distributed. Among the eight Association of Southeast Asian Nations (ASEAN) members studied here, Malaysia's footprint stayed between 3.45 and 4.16 global hectares (gha) per capita during 2010–2022, about three times Myanmar's 1.07–1.30, while Vietnam's rose by almost half, from 1.62 to 2.37 gha (Figure 1a). The candidate drivers differ just as widely. Malaysia's energy use stayed above 2,500 kg of oil equivalent per capita and Myanmar's below 450 (Figure 1c); urbanization was stable near 30% in Myanmar but nearly doubled in Cambodia, from 21% to 40% (Figure 1d); and seven of the eight economies contracted in 2020, after which Malaysia's footprint fell to 3.45 gha but was back at its 2014 peak by 2022 (Figures 1a–1b).

Three mechanisms could link these differences to the footprint. Growth raises output and consumption and, with them, the demand for resources (Eissa, 2023; Utami and Rahmayani, 2025). Energy use raises the footprint where supply is fossil-based (Destiani and Emalia, 2024; Hardi et al., 2024), which describes ASEAN, where fossil fuels supplied about 83.5% of primary energy in 2023 (ASEAN Centre for Energy, 2025). Urbanization adds demand for housing, transport, and power and converts land, reducing biocapacity (S. P. Nathaniel, 2021; Salman et al., 2022). Yet the evidence does not settle which mechanisms dominate in the region. Yusuf and Widodo (2024) find a positive growth effect among Asia-Pacific Economic Cooperation economies, while Budiarty and Emalia (2024) find it significant only among middle-income ASEAN members; the energy effect depends on the energy mix (Sharma et al., 2021) and the urbanization effect depends on innovation capacity (Salman et al., 2022). Regional evidence is fragmented. Single-country studies cover Indonesia (Hardi et al., 2024; S. P. Nathaniel, 2021) and Malaysia (Kalmaz & Awosusi, 2022)(Kalmaz, 2022), and Salman et al. (2022) cover the ASEAN-4. Panel studies of the wider bloc exist but use narrower sets of drivers. Destiani and Emalia (2024) relate economic growth and energy use to the footprint in eight ASEAN countries, and Budiarty and Emalia (2024) pair growth and energy use with trade openness. Neither estimates urbanization jointly with growth and energy use, so it remains unclear how much of the footprint is associated with the urban share once growth and energy use are held constant, and how far that association overlaps with energy use.

This study therefore examines whether economic growth, energy consumption, and urbanization are positively associated with the per capita ecological footprint in a panel of eight ASEAN members whose incomes and energy systems differ widely. It uses a balanced panel over 2010–2022, with country fixed effects that absorb stable differences between countries. It contributes in two ways. First, it estimates the three drivers jointly in one ASEAN panel, grounding urbanization in the Harris–Todaro migration framework rather than treating it as a control variable. Second, it reports how far each association holds across alternative standard-error estimators and specifications (Table 7), which matters because energy use and urbanization are highly correlated ($r = 0.795$). Growth is measured as the annual rate of GDP per capita growth rather than income level, so the estimate reflects the pace of expansion, including the 2020 contraction in seven of the eight economies. The objective is to determine the association of each factor, individually and jointly, with the ecological footprint.

HYPOTHESES DEVELOPMENT

Economic Growth

The Environmental Kuznets Curve (EKC) proposes that environmental pressure rises with income in the early stages of development, when industrialization and resource-intensive production expand, and falls only after income passes a threshold at which regulation, structural change, and cleaner technology take hold (Panayotou, 1993). This study draws on the EKC only to motivate the expected sign of the growth coefficient, not as a hypothesis to be tested. Footprint-based evidence is consistent with this ascending phase in developing economies. Growth raises the footprint in Pakistan (Danish et al., 2019), Egypt (Eissa, 2023), Indonesia (Utami and Rahmayani, 2025), eight ASEAN countries (Destiani and Emalia, 2024), and Asia-Pacific Economic Cooperation members (Yusuf and Widodo, 2024), whereas a long-run decline appears in high-income Finland (Georgescu and Kinnunen, 2024). Not every study agrees, since Budiarty and Emalia (2024) find a significant effect only among middle-income ASEAN members. Because most ASEAN members still rely on energy- and resource-intensive expansion of output, and because the model here contains a linear growth term only and does not test the curve itself, a positive association is expected. The model includes a linear growth term only: the EKC's inverted-U is defined over income levels, whereas growth here is the annual rate of GDP per capita growth, so a squared term would have no EKC interpretation. The expected positive association therefore reflects the scale effect of expanding output, and the study cannot identify an income turning point or test the inverted-U.

H1: Economic growth is positively associated with the ecological footprint in ASEAN countries.

Energy Consumption

Energy is a basic input to production alongside labor, capital, and land (Georgescu and Kinnunen, 2024; Sari and Murialti, 2025), so expanding output requires more energy. Where supply is fossil-based, as in ASEAN, higher energy use translates into more emissions and resource extraction. Consistent with this, energy use raises the footprint in the ASEAN panel (Destiani and Emalia, 2024), Indonesia (Hardi et al., 2024), Finland (Georgescu and Kinnunen, 2024), and 37 Asian countries (Ansari et al., 2020), and the effect is tied to non-renewable sources in the ASEAN-4 (Salman et al., 2022). Renewables can lower the footprint (Sharma et al., 2021; Yusuf and Widodo, 2024), but the indicator used here is total energy use per capita, which in this region is dominated by fossil sources, therefore a positive association is expected.

H2: Energy consumption is positively associated with the ecological footprint in ASEAN countries.

Urbanization

The Harris-Todaro model explains why urban populations keep growing: migrants move to cities in response to the gap between expected urban and rural incomes, even where urban jobs are scarce (Todaro and Smith, 2012), and wage and opportunity gaps likewise drive urbanization in ASEAN (Qodhari and Khudhori, 2024). The Harris–Todaro model describes migration, not environmental outcomes, so the link to the footprint runs through its consequence: a larger urban population requires housing, transport, electricity, food, and infrastructure, and expanding built-up land erodes biocapacity. A positive effect is found in the ASEAN-4, strongest in Indonesia and Thailand (Salman et al., 2022), in Indonesia, partly through non-renewable energy use (S. P. Nathaniel, 2021), among CIVETS economies (S. Nathaniel et al., 2020), and in the G7 (Ahmed et al., 2020), although results vary across Asian sub-regions (Ansari et al., 2020). Since urbanization in most ASEAN members is still in its expansion phase, a positive association is expected.

H3: Urbanization is positively associated with the ecological footprint in ASEAN countries.

Joint Association

Industrialization links the three factors: it lifts output, raises energy demand, and pulls population into cities (Todaro and Smith, 2012). Their pressures therefore overlap rather than operate separately, so estimating them one at a time risks attributing to one factor the effect of another, which argues for estimating them together. The ASEAN panel of Budiarty and Emalia (2024), for instance, includes GDP per capita, trade openness, and energy use, but not urbanization.

H4: Economic growth, energy consumption, and urbanization are jointly and significantly associated with the ecological footprint in ASEAN countries.

RESEARCH METHODS

This study employed a quantitative approach with associative design to examine the associations between economic growth, energy consumption, and urbanization and ecological footprint in ASEAN countries. The study used secondary panel data covering 2010–2022 and was analyzed using EViews 14. The population comprised the ten ASEAN member states during the study period. The sample was selected using purposive sampling based on data availability for all variables during the observation period. Eight ASEAN countries met the criteria: Indonesia, Malaysia, Thailand, the Philippines, Vietnam, Laos, Cambodia, and Myanmar, resulting in a balanced panel dataset of 104 observations with no missing values. Singapore and Brunei Darussalam were excluded due to incomplete ecological footprint data.

The data were obtained from publicly available sources. Economic growth, energy consumption, and urbanization data were sourced from the World Bank's World Development Indicators (WDI) (World Bank, 2026a, 2026b, 2026c), while ecological footprint data were obtained from the Global Footprint Network (GFN) (Global Footprint Network, 2025). Economic growth was measured by GDP per capita growth (annual %), energy consumption by energy use (kg of oil equivalent per capita), urbanization by urban population (% of total population), and ecological footprint by global hectares per capita (gha per capita). All variables were analyzed in their original units without logarithmic transformation. Because the data come from standardized international databases, no instrument validation was required.

Panel data regression was employed to estimate the associations between the independent variables and ecological footprint. This method was chosen because combining cross-country and time-series variation enlarges the number of observations and controls for unobserved country characteristics (Widarjono, 2018). The model is specified as:

$$Y_{it} = \alpha_i + \beta_1 X1_{it} + \beta_2 X2_{it} + \beta_3 X3_{it} + \varepsilon_{it}$$

Where Y_{it} is the ecological footprint per capita (gha), X1 is economic growth, X2 is energy consumption, and X3 is urbanization, measured as described above; α_i is the country-specific effect; ε_{it} is the error term; i = 1, …, 8 indexes countries; and t = 2010, …, 2022 indexes years. Model selection was conducted using the Chow and Hausman tests to determine the appropriate panel estimation model among the Common Effect Model (CEM), Fixed Effect Model (FEM), and Random Effect Model (REM). The Fixed Effect Model was selected as the appropriate model based on the model selection results. The FEM was estimated in EViews 14 by least squares with country dummy variables, using conventional standard errors.

Model diagnostics followed. Multicollinearity was assessed using the correlation matrix and variance inflation factors (VIF), heteroskedasticity using the Glejser test on the fixed effects residuals, serial correlation using the Wooldridge test with country-clustered standard errors (p-value from F (1, 7)) and cross-sectional dependence using the Breusch–Pagan LM and Pesaran CD tests. A redundant fixed effects test was used to examine whether year effects should be added. Stationarity was examined using the cross-sectionally augmented IPS (CIPS) panel unit root test of Pesaran (2007), which remains valid under cross-sectional dependence. Because the orders of integration turned out to be mixed (Section 4.1.4), cointegration was not tested formally, and a first-difference model is reported as a safeguard. To assess the reliability of the estimates under possible violations of the classical assumptions, robustness checks were conducted: standard errors clustered by period and by country, a two-way fixed effects model with country and year effects $Y_{it} = \alpha_i + \lambda_t + \beta_1 X1_{it} + \beta_2 X2_{it} + \beta_3 X3_{it} + \varepsilon_{it}$, where λ_t is the year effect, and a first-difference model. The country fixed effects model is the main specification, and the robustness checks are reported as supplementary evidence. Where the diagnostics indicate violations, significance is also judged against these checks. Hypothesis testing was conducted at the 5% significance level using the t-test, the Wald F-test on the three slope coefficients, and the overall and within coefficients of determination (R^2) to assess the partial and joint associations and explanatory power of the model. The study uses aggregate public data and no human participants, so ethics approval was not required.

RESULTS AND DISCUSSION

Descriptive Statistic

Table 1 presents 104 country-year observations, with an average ecological footprint of 1.87 gha (SD = 0.85), ranging from 1.07 gha in Myanmar to 4.16 gha in Malaysia. Explanatory variables also vary considerably across countries (Figures 1b–1d), reflecting differences between ASEAN members that are accounted for by fixed effects in the subsequent estimations.

Table 1. *Descriptive statistics of the variables*

Variable	N	Mean	SD	Min	Max
Economic Growth (X1)	104	3.75	3.66	-12.63	8.82
Energy Consumption (X2)	104	1,017.87	808.00	294.99	3,035.37
Urbanization (X3)	104	44.78	14.77	21.22	75.97
Ecological Footprint (Y)	104	1.87	0.85	1.07	4.16

Model Selection

Table 2. *Chow Test*

Effect Test	Statistics	d.f	Prob.
Cross-section F	42.886508	(7,93)	0.0000
Cross-section Chi-square	149.940234	7	0.0000

Table 3. *Hausman Test*

Test Summary	Statistics	d.f	Prob.
Cross-section random	15.15489	3	0.0017

The Chow test results presented in Table 2 indicate that the Cross-section Chi-Square probability value is 0.0000, which is less than 0.05. Since the probability value is lower than the 5% significance level, the FEM is the more appropriate model to apply. The Hausman test results in Table 3 indicate that the probability value for the Cross-section Random effect is 0.0017, which is less than 0.05. Since the probability value is below the 5% significance level, the FEM is the more appropriate model for this study. The fixed effects model is therefore estimated in Section 4.1.5 and checked with the diagnostic tests below.

Fixed effects estimation is also appropriate conceptually, because the eight countries are the units of interest rather than a random draw from a larger population, and it remains consistent whether or not the random effects assumptions hold.

Diagnostic Test

After the Fixed Effects Model (FEM) was selected, diagnostic tests assessed the validity and reliability of the estimates, covering multicollinearity, heteroskedasticity, serial correlation, and cross-sectional dependence. Residual-based tests used the FEM residuals from Section Panel Data Regression Estimation (Napitupulu et al., 2021:120). able 4 shows correlations of -0.170864 (X_1–X_2), -0.203870 (X_1–X_3), and 0.795423 (X_2–X_3). Although the X_2–X_3 correlation is relatively high, all values remain below 0.85, with VIF values far below 5. Thus, multicollinearity is unlikely to be a serious concern, although the separate effects of energy consumption and urbanization should be interpreted cautiously.

Table 4. *Multicollinearity Test Results*

	X1	X2	X3
X1	1.000000	-0.170864	-0.203870
X2	-0.170864	1.000000	0.795423
X3	-0.203870	0.795423	1.000000
VIF	1.04	2.72	2.76

Table 5. *Diagnostic Test Results*

Diagnostic	Test	Statistic	Prob.	Conclusion
Heteroskedasticity	Glejser	X1: t = -3.04; X2: t = 1.34; X3: t = 0.03	0.003; 0.182; 0.978	Present
Serial correlation	Wooldridge	F (1, 7) = 6.85	0.035	Present
Cross-sectional dependence	Breusch-Pagan LM	77.81 (df 28)	0.000	Present
	Pesaran scaled LM	6.66	0.000	Present
	Bias-corrected scaled LM	6.32	0.000	Present
	Pesaran CD	-1.30	0.194	Not rejected

Heteroskedasticity was tested with the Glejser test, which regresses the absolute residuals of the fixed effects model on the explanatory variables. Economic growth is significantly and negatively related to the absolute residuals (p = 0.003), whereas energy consumption (p = 0.182) and urbanization (p = 0.978) are not, indicating heteroskedasticity: the error variance is larger when growth is weak.

Serial correlation was tested with the Wooldridge (2002) test for panel data. The null hypothesis of no first-order serial correlation is rejected (F (1,7) = 6.85, p = 0.035), consistent with the Durbin–Watson statistic of 0.573 reported in Table 6.

Cross-sectional dependence was tested on the residuals of the fixed effects model. The Breusch–Pagan LM (77.81, p = 0.000), Pesaran scaled LM (6.66, p = 0.000), and bias-corrected scaled LM (6.32, p = 0.000) tests reject the null of no dependence across countries, whereas the Pesaran CD test does not (−1.30, p = 0.194). Because the panel has fewer cross-sections (8) than periods (13), the Breusch–Pagan LM test is the most appropriate, so the residuals are treated as cross-sectionally dependent.

Because heteroskedasticity, serial correlation, and cross-sectional dependence are present, conventional standard errors may be unreliable, and the level estimates may partly reflect common trends rather than a stable long-run relationship. Section 4.1.6 therefore reports robustness checks (Table 7).

Panel Unit Root Test

Because the diagnostics show cross-sectional dependence, stationarity was tested with the Pesaran (2007) CIPS panel unit root test, which allows for it, with a maximum lag of one and the null hypothesis of a unit root. The footprint has a unit root in levels with a constant (CIPS = −1.940 > −2.46) and with a constant and trend (−2.493 > −3.13), and is stationary in first differences (−3.239 < −2.49), so it is I (1). Economic growth has a unit root with a constant only (−1.908 > −2.46) but is stationary around a trend (−4.949 < −3.13). Urbanization is stationary in levels under both specifications (−3.644 < −2.46 and −4.212 < −3.13). Energy consumption has a unit root in levels (−1.846 > −2.46 with a constant; −1.208 > −3.13 with a constant and trend) and still has one in first differences (−1.828 > −2.49; −2.524 > −3.20), so its order of integration is inconclusive; with eight countries and at most 13 periods, the test has low power. Because the orders of integration are mixed or inconclusive, cointegration could not be reliably assessed, and the level estimates in Section 4.1.5 may be partly spurious. The first-difference model in Table 7 therefore serves as a safeguard.

Panel Data Regression Estimation

Based on the model suitability tests, the Fixed Effect Model (FEM) was selected. The estimation results yielded the following panel data regression equation:

$$Y_{it} = \hat{\alpha}_i + 0.012041X_{1it} + 0.000689X_{2it} + 0.013636X_{3it}$$

where $\hat{\alpha}_i$ is the country-specific intercept, which averages C = 0.517483 across the eight countries. Based on this model, the interpretation of each variable is as follows:

The constant (C) of 0.517483 is the average of the eight country-specific intercepts. Because each country has its own intercept, it is not interpreted separately.

The Economic Growth variable (X1) has a coefficient of 0.012041 with a probability of 0.0096. This means that Economic Growth is positively and significantly associated with the Ecological Footprint. A one-percentage-point higher GDP per capita growth rate is associated with a 0.012041 gha per capita higher Ecological Footprint on average within a country, assuming other variables remain constant.

The Energy Consumption variable (X2) has a coefficient of 0.000689 with a probability of 0.0001. This means that Energy Consumption is positively and significantly associated with the Ecological Footprint. An increase in energy use of 1 kg oil equivalent/capita is associated with a 0.000689 gha per capita higher Ecological Footprint on average within a country, assuming other variables remain constant.

The Urbanization variable (X3) has a coefficient value of 0.013636 with a probability of 0.0102. This indicates that urbanization is positively and significantly associated with the Ecological Footprint. A one-percentage-point higher urban population share is associated with a 0.013636 gha per capita higher Ecological Footprint on average within a country, holding the other variables constant.

A redundant fixed effects test shows that year effects are jointly insignificant ($F = 0.44$, $p = 0.941$; $\chi^2 = 6.59$, $p = 0.883$), so the country fixed effects model is retained as the main specification and the two-way model is reported as a robustness check (Table 7).

Table 6. *Fixed Effect Model Estimation Results*

Panel A. Coefficients				
Variable	**Coefficient**	**Std. Error**	**t-Statistics**	**Prob.**
C	0.517483	0.209407	2.471180	0.0153
X1	0.012041	0.004553	2.644318	0.0096
X2	0.000689	0.000172	4.016774	0.0001
X3	0.013636	0.005197	2.623922	0.0102
Panel B. Model statistics				
Statistic	**Value**		**Statistic**	**Value**
Observations / countries / periods	104/8/13		Mean dependent var	1.874587
R-squared (overall, incl. country effects)	0.968737		S.D. dependent var	0.853051
Adjusted R-squared	0.965375		S.E. of regression	0.158733
Within R-squared	0.344		Sum squared resid	2.343249
Wald F-test, X1–X3 jointly (df 3, 93)	16.26592	(p = 0.0000)	Log likelihood	49.65872
F-statistic (regressors and country effects; df 10, 93)	288.1756	(p = 0.0000)	Akaike / Schwarz / Hannan-Quinn	−0.743437 / −0.463742 / −0.630124
Durbin-Watson stat	0.572948		Effects specification	Cross-section fixed (dummy variables)

Robustness Checks

Table 7. *Robustness Checks*

	(1) Main FEM	(2) SE by clustered period	(3) SE by clustered country	(4) Two-way FE	(5) First difference
X1 Growth	0.012041 (0.004553) [0.0096]	0.012041 (0.002912) [0.0014]	0.012041 (0.007658) [0.1599]	0.014143 (0.007822) [0.0743]	0.006926 (0.002688) [0.0115]
X2 Energy	0.000689 (0.000172) [0.0001]	0.000689 (0.000180) [0.0024]	0.000689 (0.000377) [0.1103]	0.000681 (0.000245) [0.0067]	0.000923 (0.000171) [0.0000]
X3 Urbanization	0.013636 (0.005197) [0.0102]	0.013636 (0.003065) [0.0008]	0.013636 (0.003925) [0.0104]	0.015651 (0.008034) [0.0549]	0.009231 (0.011224) [0.4129]
Country effects	Yes	Yes	Yes	Yes	Differenced out
Year effects	No	No	No	Yes	No
Observations	104	104	104	104	96

Note: With only eight clusters, country-clustered standard errors are likely imprecise

The sign and magnitude of the three coefficients are stable across the specifications, but their statistical significance depends on the estimator. Energy consumption is significant at the 5% level in four of the five specifications and is the most robust association. Economic growth and urbanization are significant in three of five. With standard errors clustered by country, which address serial correlation, only urbanization remains significant. Urbanization is stationary in levels, so differencing discards much of its variation and its first-difference result should not be over-interpreted. The results should therefore be read as consistent positive associations of varying statistical strength, not as precisely estimated effects.

Hypothesis Testing

Based on Table 6, the associations between the independent variables and the dependent variable are as follows. Economic Growth (X1) has a calculated t-value of 2.644318, greater than the t-table value of 1.9858, with a significance value of 0.0096, below 0.05. Thus, H1 was supported in the main specification, indicating that Economic Growth is positively and significantly associated with the Ecological Footprint.

Energy Consumption (X2) has a calculated t-value of 4.016774, greater than the t-table value of 1.9858, with a significance value of 0.0001, below 0.05. Thus, H2 was supported in the main specification, indicating that Energy Consumption is positively and significantly associated with the Ecological Footprint.

Urbanization (X3) has a calculated t-value of 2.623922, greater than the t-table value of 1.9858, with a significance value of 0.0102, below 0.05. Thus, H3 was supported in the main specification, indicating that Urbanization is positively and significantly associated with the Ecological Footprint.

The robustness checks in Table 7 show that these results are sensitive to the standard-error estimator: energy consumption is significant in four of the five specifications, whereas growth and urbanization are significant in three.

The simultaneous test uses a Wald F-test on the three slope coefficients and yields an F-statistic of 16.2659 (df 3, 93) with $p < 0.001$ (Table 6). The null hypothesis (H_0) is therefore rejected, signifying that economic growth, energy consumption, and urbanization are jointly and significantly associated with the ecological footprint in ASEAN countries during 2010–2022, so H4 is supported in the main specification. The F-statistic reported by EViews (288.1756; df 10, 93) also includes the country effects and is therefore not used to test H4.

Table 6 reports two measures of fit. The overall R^2 of 0.9687 includes the country-specific intercepts and therefore does not measure the explanatory power of the three regressors alone. The within R^2 of 0.344 does: growth, energy consumption, and urbanization account for about 34.4% of the variation in the footprint within countries over time, and the rest is due to other factors.

Discussion

The estimates below are statistical associations from observational panel data. The mechanisms invoked (scale effect, energy as a factor of production, migration-driven urban expansion) are theoretical interpretations that the design cannot test, and no causal pathway is identified. Because the diagnostics (Table 5) show serial correlation, heteroskedasticity, and cross-sectional dependence, significance is also judged against the robustness checks (Table 7).

Economic Growth and Ecological Footprint

Growth is positively and significantly associated with the footprint (0.012, p = 0.0096), so H1 is supported in the main specification: a one-percentage-point higher growth rate goes with a 0.012 gha higher footprint. The association is less robust than that of energy, since it loses significance with country-clustered standard errors (p = 0.160) and year effects (p = 0.074) (Table 7). One possible explanation is that growth in most ASEAN members remains resource- and energy-intensive, although industrial structure is not measured here. The positive sign is consistent with the scale effect that motivates the ascending phase of the Environmental Kuznets Curve (Panayotou, 1993), although this study does not test the curve, and with findings for Egypt (Eissa, 2023), Pakistan (Danish et al., 2019), Indonesia (Utami et al., 2025), and APEC (Yusuf and Widodo, 2024). It partly differs from Budiarty and Emalia (2024), who find the effect significant only in middle-income ASEAN members, and from high-income Finland (Georgescu and Kinnunen, 2024); a linear term cannot test either contrast or a turning point. Differences from earlier studies may also reflect geographical coverage, sample, period, or variable definitions, which this study cannot verify. The effect is small (about 0.043 gha per within-country standard deviation), so the evidence does not support restraining growth itself, but it supports pairing growth strategies with environmental targets.

Energy Consumption an Ecological Footprint

Energy use is positively and significantly associated with the footprint (0.000689, p = 0.0001), so H2 is supported in the main specification and in four of five specifications in Table 7, making it the most robust association: 100 kg of oil equivalent per capita goes with a 0.069 gha higher footprint, about 0.075 gha per within-country standard deviation, or roughly 40% of the footprint's within-country standard deviation (0.19 gha). With fossil fuels supplying about 83.5% of ASEAN primary energy (ASEAN Centre for Energy, 2025), more energy use plausibly means more emissions and more land needed to absorb them, in line with energy as a factor of production and with Destiani and Emalia (2024), Hardi et al. (2024), and Ansari et al. (2020). Because energy and urbanization are correlated (r = 0.795; VIF = 2.72), the coefficient may partly capture urban energy demand. Total energy use also cannot show whether renewables weaken the link (Sharma et al., 2021; Yusuf and Widodo, 2024), so differences from studies in other settings may reflect energy composition. Energy efficiency and renewable deployment, especially where use is rising quickly (such as Vietnam), are therefore the best-supported priorities, but as an association the coefficient cannot predict a policy's footprint reduction.

Urbanization and Ecological Footprint

Urbanization is positively and significantly associated with the footprint (0.013636, p = 0.0102), so H3 is supported in the main specification: one percentage point more urban population goes with 0.014 gha more footprint. It stays significant with clustered standard errors (p = 0.001 and 0.010) but weakens with year effects (p = 0.055) and is insignificant in first differences (p = 0.413), so it is less robust than energy. The variation comes mostly from fast-urbanizing members such as Cambodia (21% to 40%) and little from Myanmar (Figure 1d). The Harris–Todaro reasoning (Todaro and Smith, 2012) suggests migration enlarges demand for housing, transport, and power and converts land, in line with Salman et al. (2022), Nathaniel (2021), Nathaniel et al. (2020), and Ahmed et al. (2020), but migration is not measured. Given the overlap with energy (r = 0.795; VIF = 2.76), part of this association may operate through energy use, which is consistent with its weaker estimates in the other specifications, although this overlap is not tested here. Compact, transit-oriented planning is therefore better framed as a supporting measure. Taken literally,

Cambodia's 19-point rise corresponds to about 0.26 gha, which illustrates the association's size and is not a predicted effect.

Joint Association of Economic Growth, Energy Consumption, and Urbanization with Ecological Footprint

A Wald test on the three slope coefficients shows they are jointly significant ($F = 16.27$; $df = 3, 93$; $p < 0.001$), so H4 is supported in the main specification, consistent with industrialization lifting output, energy demand, and urban population together (Todaro and Smith, 2012). The overall R^2 (0.9687) includes the country intercepts; the within R^2 (0.344) shows what the three regressors explain within countries. The fixed effects absorb stable differences, so the results cannot explain why Malaysia's footprint is about three times Myanmar's.

The associations may also reflect omitted factors. Industrial structure, regulation, and cleaner technology are what the Kuznets argument identifies as shaping the income-environment link (Panayotou, 1993); renewable penetration may weaken the energy link (Sharma et al., 2021; Yusuf and Widodo, 2024); trade can shift resource use across borders (Budiarty and Emalia, 2024 include it); and innovation capacity may change the footprint per unit of output or per urban resident (Salman et al., 2022). None is measured, so coefficients may be biased in either direction.

Limitations: the sample covers eight members and excludes Singapore and Brunei. The diagnostics show serial correlation (Wooldridge $F(1,7) = 6.85$, $p = 0.035$; Durbin–Watson = 0.57), which can understate standard errors and overstate significance. With country-clustered standard errors only urbanization remains significant, although eight clusters make these estimates imprecise. The Chow and Hausman tests assume classical errors, so model selection may be affected, although the country effects are large and fixed effects estimation is consistent either way, and the unit root test has limited power at $T = 13$, while cointegration could not be assessed because the orders of integration are mixed. The significance levels are therefore indicative, with energy the most robust, and the associations are not causal. The policy implications are therefore qualitative rather than quantitative.

CONCLUSION

This study examined the association of economic growth, energy consumption, and urbanization with the ecological footprint of eight ASEAN countries (Indonesia, Malaysia, Thailand, the Philippines, Vietnam, Laos, Cambodia, and Myanmar) during 2010–2022, using a fixed effects panel model that estimates the three drivers jointly across members at very different income and energy levels. In the main model, each factor is positively and significantly associated with the footprint, and the three are jointly significant. Energy consumption is the most robust association, remaining significant in four of five specifications, whereas the significance of growth and urbanization depends on how standard errors are estimated. These are statistical associations, not causal effects, and they apply to the sampled countries, not to all ASEAN members. They are also limited by serial correlation, heteroskedasticity, cross-sectional dependence, a short time dimension ($T = 13$), and omitted factors such as industrial structure, renewable energy, and trade, so the significance levels are indicative.

With these caveats, energy efficiency and a faster shift to renewable energy are the best-supported policy priorities, followed by compact, transit-oriented urban planning in fast-urbanizing members, while growth strategies should be paired with environmental targets rather than constrained. Future studies could add renewable energy shares, trade, and industrial structure, test nonlinear growth effects using income levels, and use estimators robust to serial correlation, heteroskedasticity, and cross-sectional dependence.

DECLARATIONS

Use Of Artificial Intelligence

Generative AI (Claude, Anthropic) was used for language editing, checking the manuscript for compliance with journal templates and citation styles, and assisting in the revision of the manuscript in response to reviewers' comments. The authors performed all assessments, reviews, and revisions, verified all content, and assume full responsibility for the manuscript.

Author Contributions

Mutia Adinda Putri — Conceived the study, compiled the data, conducted the estimation, interpreted the results, and prepared the original draft, which is based on her undergraduate thesis.

Tri Kurniawati — Served as the corresponding author. Both authors approved the final manuscript.

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Conflict of Interest

The authors declare no conflict of interest.

REFERENCES

Ahmed, Z., Zafar, M. W., Ali, S., & Danish. (2020). Linking urbanization, human capital, and the ecological footprint in G7 countries: An empirical analysis. *Sustainable Cities and Society, 55*, Article 102064. https://doi.org/10.1016/j.scs.2020.102064

Ansari, M. A., Haider, S., & Khan, N. A. (2020). Environmental Kuznets curve revisited: An analysis using ecological and material footprint. *Ecological Indicators, 115*, Article 106416. https://doi.org/10.1016/j.ecolind.2020.106416

ASEAN Centre for Energy. (2025). *ASEAN energy statistics leaflet 2025*. https://aebf.aseanenergy.org/publications/asean-energy-statistics-leaflet-2025/

Beton Kalmaz, D., & Awosusi, A. A. (2022). Investigation of the driving factors of ecological footprint in Malaysia. *Environmental Science and Pollution Research, 29*(37), 56814–56827. https://doi.org/10.1007/s11356-022-19797-5

Budiarty, I., & Emalia, Z. (2024). Ecological footprint study as an indicator of sustainable economic development in ASEAN countries. In *Proceedings of the 7th International Conference of Economics, Business, and Entrepreneurship, ICEBE 2024, 4–5 September 2024, Shah Alam, Selangor, Malaysia*. EAI. https://doi.org/10.4108/eai.4-9-2024.2353812

Danish, Hassan, S. T., Baloch, M. A., Mahmood, N., & Zhang, J. W. (2019). Linking economic growth and ecological footprint through human capital and biocapacity. *Sustainable Cities and Society, 47*, Article 101516. https://doi.org/10.1016/j.scs.2019.101516

Destiani, E., & Emalia, Z. (2024). Pembangunan ekonomi berkelanjutan dan daya dukung lingkungan berbasis jejak ekologis di negara ASEAN. *Journal on Education, 6*(4), 18782–18791. https://doi.org/10.31004/joe.v6i4.5859

Eissa, A. A. E. (2023). Investigating the relationship between economic growth and ecological footprint in Egypt. *MSA-Management Science Journal, 2*(3), 112–145. https://doi.org/10.21608/msamsj.2023.257398.1047

Georgescu, I., & Kinnunen, J. (2024). Sustainability effects of FDI, GDP and energy use on ecological footprint in Finland: An ARDL approach. *World Development Sustainability, 4*, Article 100157. https://doi.org/10.1016/j.wds.2024.100157

Global Footprint Network. (2025). *Earth Overshoot Day 2025 falls on July 24th* [Press release]. https://overshoot.footprintnetwork.org/newsroom/press-release-2025-english/

Hardi, I., Afjal, M., Can, M., Idroes, G. M., Noviandy, T. R., & Idroes, R. (2024). Shadow economy, energy consumption, and ecological footprint in Indonesia. *Sustainable Futures, 8*, Article 100343. https://doi.org/10.1016/j.sftr.2024.100343

Lo, K., Miller, E., Dworatzek, P., Basnet, N., Silva, J., Van Berkum, J. L., Halldórsdóttir, R. B., & Dyck, M. D. R. (2025). *National ecological footprint and biocapacity accounts, 2025 edition* (Version 1.0) [Data set]. Footprint Data Foundation. https://footprint.info.yorku.ca/data/

Napitupulu, R. B., Simanjuntak, T. P., Hutabarat, L., Damanik, H., Harianja, H., Lumbantobing, C. E. R., & Sirait, R. T. M. (2021). *Penelitian bisnis: Teknik dan analisa data dengan SPSS, Stata, dan EViews*. Madenatera.

Nathaniel, S. P. (2021). Ecological footprint, energy use, trade, and urbanization linkage in Indonesia. *GeoJournal, 86*(5), 2057–2070. https://doi.org/10.1007/s10708-020-10175-7

Nathaniel, S., Nwodo, O., Sharma, G., & Shah, M. (2020). Renewable energy, urbanization, and ecological footprint linkage in CIVETS. *Environmental Science and Pollution Research, 27*(16), 19616–19629. https://doi.org/10.1007/s11356-020-08466-0

Panayotou, T. (1993). *Empirical tests and policy analysis of environmental degradation at different stages of economic development* (Working Paper No. 238). International Labour Office, Technology and Employment Programme.

Pesaran, M. H. (2007). A simple panel unit root test in the presence of cross-section dependence. *Journal of Applied Econometrics, 22*(2), 265–312. https://doi.org/10.1002/jae.951

Qodhari, D., & Khudhori, K. U. (2024). Determinan peningkatan urbanisasi di negara-negara ASEAN. *Jurnal Magister Ekonomi Syariah, 3*(1), 79–90. https://doi.org/10.14421/jmes.2024.031-05

Salman, M., Zha, D., & Wang, G. (2022). Interplay between urbanization and ecological footprints: Differential roles of indigenous and foreign innovations in ASEAN-4. *Environmental Science & Policy, 127*, 161–180. https://doi.org/10.1016/j.envsci.2021.10.016

Sari, A. D., & Murialti, N. (2025). Pengaruh konsumsi energi dan energi terbarukan terhadap perkembangan industri dikawasan ASEAN. *Jurnal Pendidikan Tambusai, 9*(1), 4627–4633. https://doi.org/10.31004/jptam.v9i1.25111

Sharma, R., Sinha, A., & Kautish, P. (2021). Does renewable energy consumption reduce ecological footprint? Evidence from eight developing countries of Asia. *Journal of Cleaner Production, 285*, Article 124867. https://doi.org/10.1016/j.jclepro.2020.124867

Todaro, M. P., & Smith, S. C. (2012). *Economic development* (11th ed.). Pearson.

Utami, S. D., & Rahmayani, D. (2025). Analisis determinan jejak ekologi di Indonesia: Pendekatan ARDL. *COSTING: Journal of Economic, Bussines and Accounting, 8*(3), 4342–4356. https://doi.org/10.31539/costing.v8i3.15811

Wackernagel, M., & Galli, A. (2007). An overview on ecological footprint and sustainable development: A chat with Mathis Wackernagel. *International Journal of Ecodynamics, 2*(1), 1–9. https://doi.org/10.2495/ECO-V2-N1-1-9

Widarjono, A. (2018). *Ekonometrika: Pengantar dan aplikasinya disertai panduan EViews* (5th ed.). UPP STIM YKPN.

Wooldridge, J. M. (2002). *Econometric analysis of cross section and panel data*. MIT Press.

World Bank. (n.d.-a). *Energy use (kg of oil equivalent per capita* [Data set]. World Development Indicators. https://data.worldbank.org/indicator/EG.USE.PCAP.KG.OE

World Bank. (n.d.-b). *GDP per capita growth (annual %* [Data set]. World Development Indicators. https://data.worldbank.org/indicator/NY.GDP.PCAP.KD.ZG

World Bank. (n.d.-c). *Urban population (% of total population* [Data set]. World Development Indicators. https://data.worldbank.org/indicator/SP.URB.TOTL.IN.ZS

Yusuf, M. I., & Widodo, W. (2024). Analisis pengaruh pertumbuhan ekonomi terhadap ecological footprint: Studi kasus negara-negara anggota APEC. *Diponegoro Journal of Economics, 13*(4), 29–36. https://doi.org/10.14710/djoe.45929