

Uncovering the Structural Drivers of Carbon Emissions in Malaysia: Energy Demand vs. Macroeconomic Determinants

Nur Liyana Awang¹, *Nur Zahidah Bahrudin², Hazriah Hasan³, Muhammad Fariz Helmi Husain⁴, Nelmidia⁵

¹Faculty of Business and Management, UiTM, Shah Alam, Selangor, Malaysia

²Faculty of Business and Management, UiTM, Puncak Alam, Selangor, Malaysia

³Faculty of Entrepreneurship and Business, Universiti Malaysia Kelantan, Kelantan, Malaysia

⁴Cyberview Sdn. Bhd. Malaysia

⁵Transportation and Logistics Institute, Trisakti, Indonesia

Email: 2025277038@student.uitm.edu.my, *zahidah1002@uitm.edu.my, hazriah.h@umk.edu.my, farizhelmi@gmail.com, ne01.nelmidia@lecturer.itltrisak-ti.ac.id

Corresponding Author: Dr Nur Zahidah Bahrudin

Abstract: Rapid industrialization and urbanization in Malaysia have driven substantial economic expansion alongside a sharp escalation in carbon dioxide (CO₂) emissions, creating a major policy tension regarding its commitment to reduce carbon intensity by 45% by 2030. This study examines the symmetric and asymmetric long-term relationships, cointegration, and dynamic causality among GDP, energy consumption, renewable energy, urbanization, industrialization, and CO₂ emissions within a unified dynamic framework. Empirical results reveal that energy consumption is the sole statistically significant driver of Malaysia's long-run carbon emissions, whereas GDP, renewable energy, urbanization, and industrialization exert no statistically significant direct impact. Crucially, the statistical insignificance of GDP refutes the applicability of the Environmental Kuznets Curve (EKC) hypothesis in Malaysia, demonstrating that higher income levels will not automatically induce environmental recovery past a specific development threshold. Therefore, policymakers cannot rely on passive economic growth to achieve sustainability. To effectively decouple economic progress from carbon output, national frameworks must move beyond income-driven assumptions and implement targeted interventions focused on direct energy demand management, fossil fuel subsidy reforms, and aggressive clean-energy substitution.

Keywords: Sustainability, Carbon Dioxide (CO₂) emissions, industrialization, urbanization, time-series, long-run, ARDL, Malaysia

1. Introduction and Background

Malaysia has undergone substantial industrialization and urbanization over recent decades, driving national economic expansion while precipitating a sharp escalation in carbon dioxide (CO₂) emissions (Awosusi et al., 2024). This environmental footprint is evident in historical trends: national CO₂ emissions surged from approximately 3,568 kilotons (kt) in 1960 to 56,190 kt in 1990, reaching over 295,000 kt in recent years due to accelerated manufacturing, energy consumption, and infrastructure expansion (Raihan et al., 2022; World Bank, 2024). Concurrently, Malaysia's urbanization rate increased from 25% in 1960 to nearly 79% (World Bank, 2024), expanding urban transport networks, heavy construction, and industrial energy demand. Notably, Malaysia records significantly higher per capita CO₂ emissions than many of its Southeast Asian neighbors (Harun et al., 2021), establishing a pressing need to re-examine the structural drivers of its national carbon trajectory.

This environmental trend creates a sharp policy tension between sustaining economic development gains and meeting the country's voluntary commitment to reduce carbon intensity by 45% by 2030 relative to 2005 levels (Raihan et al., 2022). Addressing this challenge requires a systemic perspective because isolated environmental interventions across energy, industrial output, and urban planning generate complex, interconnected side effects. Although fossil fuel dependency remains the primary driver of national emissions, expanding renewable energy deployment offers a viable mechanism to harmonize economic growth with environmental sustainability (Raihan & Tuspekova, 2022). However, decoupling economic output from fossil fuel consumption requires targeted policy alignment. Recent evidence indicates that expanding clean energy generation, particularly when linked with energy subsidy reforms, is far more aligned with Malaysia's emissions targets than maintaining coal- and gas-dominated power mixes (Yahoo et al., 2024).

From a theoretical perspective, the dynamic interaction between economic expansion and environmental quality is frequently anchored in the Environmental Kuznets Curve (EKC) hypothesis, which posits an inverted U-shaped relationship where environmental degradation initially worsens with income growth but declines once a country reaches higher development thresholds (Afroz et al., 2022). However, empirical evidence regarding Malaysia's determinants reveals complex, non-linear dynamics. For instance, urbanization has been shown to initially lower emissions before increasing them past a specific threshold, while simultaneously Granger-causing CO₂ emissions (Shahbaz et al., 2016). Similarly, total energy consumption exerts a dominant long-run positive effect on emissions, with unidirectional causality running from energy use to carbon output (Raihan et al., 2022). These findings imply that policies relying strictly on aggregate economic growth or total energy demand risk ignoring structural differences across urban centers, industrial subsectors, and clean-energy transitions.

Despite the growing body of empirical literature, a critical gap remains: existing research on Malaysia frequently fails to account for both symmetric and asymmetric impacts when evaluating how the country's energy-intensive industrial evolution shapes its environmental footprint (Bi et al., 2024; Ha et al., 2024). Grounded in the Environmental Kuznets Curve (EKC) framework, GDP, industrialization, total energy consumption, and urbanization initially aggravate emissions through the scale effect during rapid economic expansion. Over time, structural economic shifts (composition effect) and the adoption of cleaner energy sources, such as renewable energy (technique effect), determine whether emissions can be decoupled from economic activity. However, macroeconomic and energy shocks often trigger non-linear or disproportionate responses in emissions depending on whether these drivers experience positive or negative shifts. Assuming purely linear or symmetric relationships can lead to biased dynamic estimation and flawed policy conclusions. Furthermore, few studies evaluate GDP, energy consumption, renewable energy, urbanization, and industrialization within a unified dynamic framework that distinguishes short-term cyclical shocks from durable structural adjustments. Establishing whether feedback loops exist (bidirectional causality) is equally essential, as it indicates whether economic and energy decisions both drive and react to environmental conditions (Shahbaz et al., 2016).

To address these empirical and theoretical gaps, this study sets out to achieve three interconnected objectives: first, to investigate the symmetric and asymmetric long-term effects of GDP, energy consumption, renewable energy, urbanization, and industrialization on Malaysia's carbon emissions. The second objective is to evaluate whether a stable long-run cointegrating relationship exists among these determinants in a unified framework. Moreover, the third objective aims to uncover the direction of dynamic causality among the variables to distinguish immediate economic adjustment costs from persistent sustainability outcomes.

By establishing the dynamic and causal architecture of Malaysia's emissions process, this research provides a robust empirical foundation to recalibrate national development models toward greater ecological efficiency (Hou et al., 2025; Malik et al., 2022). These insights are particularly relevant as Malaysia transitions from a resource-based economy toward high-value manufacturing and service sectors (Segar et al., 2024). Differentiating short-term emission reactions from long-term structural trends will equip policymakers with the evidence necessary to sequence targeted energy substitution strategies, reform fossil fuel subsidies, and integrate sustainable urban planning frameworks into Malaysia's long-term growth agenda.

2. Literature Review

Theoretical frameworks assessing the nexus between economic activity and environmental degradation often utilize the Environmental Kuznets Curve hypothesis model to elucidate the driving forces behind carbon emissions (Borsha et al., 2024). These theories emphasize that while increased income levels initially exacerbate ecological stress due to resource-intensive industrialization, maturation may eventually foster technological efficiency that reduces carbon intensity (Iqbal et al., 2024; Kraujalienė et al. 2026). Empirical literature specific to Malaysia reveals conflicting evidence regarding these models, with some studies validating the Kuznets curve (Afroz et al., 2024), while others emphasize that urbanization and economic growth persistently exacerbate emissions (Adeleye et al., 2021; El-Aal et al., 2024). Specifically, while some research highlights a positive correlation between energy consumption and carbon output (Bouchoucha et al., 2024), other empirical findings suggest that the Environmental Kuznets Curve remains invalid within the Malaysian

context (Raihan, 2024). Consequently, identifying research gaps requires addressing the inconsistency in how renewable energy integration and technological innovation are modelled as mitigation strategies within the national framework (Gazi et al., 2022; Raihan & Voumik, 2022).

Further, despite existing studies confirming that economic expansion and energy utilization remain the primary drivers of environmental contamination, the mechanisms by which structural transformation influences these outcomes remain insufficiently explored (Gyamfi et al., 2021). Recent academic discourse underscores that the comprehensive potential of technological innovation and forest sequestration in Malaysia remains under-researched despite their hypothesized mitigation benefits (Raihan & Tuspekova, 2023). Furthermore, although existing literature often focuses on the broader Southeast Asian region, there is a lack of granular analysis regarding how Malaysia's specific industrial composition and energy-intensive tourism sector interact to alter national emission trajectories (Derouez & Ifa, 2025; Raihan et al., 2023). Moreover, extant research frequently utilizes cross-sectional data, which fails to adequately capture the dynamic, time-varying nature of these causal relationships within Malaysia's rapidly evolving economic landscape (Khosravi et al., 2024). Furthermore, while literature has extensively examined the emissions-energy nexus in contexts such as Pakistan, empirical consensus on the directionality of these variables in the Malaysian sector remains elusive (Tanveer et al., 2021). Prior studies using the autoregressive distributed lag approach indicate that energy consumption and economic expansion exert a positive, significant impact on carbon output without a reciprocal influence from emissions on economic performance (Falade & Adeyemi, 2023; Hu et al., 2021). Such conflicting empirical results underscore a critical research gap regarding whether existing energy policies are effectively decoupling growth from carbon intensity (Raihan, 2023; Supriyanto et al., 2022). Additionally, current scholarly efforts have largely overlooked the distinct environmental consequences of specialized energy sources, particularly the ecological trade-offs associated with emerging hydroelectric and renewable technologies in Southeast Asian nations (Awosusi et al., 2025).

Empirical Findings on the Variables

Relationship between GDP and CO₂ emissions

There have been many empirical studies that prove there is a strong link between increased GDP and CO₂ emissions. According to Suhartoko & Ekaristi (2023), economic development acts as one of the determinants of CO₂ emissions along with factors like population change, FDI, and fossil fuels. The authors use a fixed effects panel regression model that shows a significant positive relationship between GDP and CO₂ emissions, which implies that CO₂ emissions increase along with economic development. The authors believe that this could be attributed to the level of development of ASEAN countries because production requires more energy. Similarly, Sahputra et al. (2025) highlighted the close relationship between economic growth, energy consumption, and CO₂ emissions, stating that economic growth in developing countries is often accompanied by increasing energy demand. However, the study also emphasized that economic growth could improve the environment with the adoption of cleaner energy sources and sustainable energy practices. This indicates that the environmental impact of economic growth not only relies on the level of economic development but also on the nature of energy usage. According to Sugiharti et al. (2025), GDP is one of the key determinants of carbon emissions. Further, the findings concluded that there is a positive relationship between GDP and CO₂ emissions. **H1:** Gross Domestic Product (GDP) has a significant effect on CO₂ emissions.

Relationship between Energy Consumption and CO₂ Emissions

A study carried out by Saboori & Sulaiman (2013) examined the interrelationships between energy consumption, economic growth, and CO₂ emissions in five ASEAN countries. The findings of their study suggest that there is a significant and positive impact of energy consumption on CO₂ emissions in both the short and long term. The findings demonstrated that the elasticity of CO₂ emissions in relation to energy consumption was greater in the long run than the short-run elasticity of the two variables. Thus, it suggested that the environmental consequences of energy consumption become more severe as time progresses. In addition, all five countries exhibit a direct correlation between energy consumption and CO₂ emissions, and there was a bidirectional causal relationship between energy consumption and CO₂ emissions found by using the Granger causality test results.

According to Sugiharti et al. (2025), there is a positive correlation between increased total energy use and

energy intensity in ASEAN countries with CO₂ emissions because, as economies use more energy for production purposes, the environment faces more pressures than decreases. This paper uses data from 1990 to 2021 and applies a STIRPAT-based model using the CCEMG estimation method due to econometric issues related to cross-sectional dependence and heterogeneity in panel data analysis. The authors found a positive connection between CO₂ emissions and GDP growth rate, population growth rate, and energy intensity, interpreting their results as increased economic activity and population pressure that led to increased energy demand and caused environmental pollution.

H2: Energy consumption has a significant impact on CO₂ emissions

Relationship between Renewable Energy and CO₂ Emissions

Renewable energy has also become one of the vital elements of sustainable development policies due to its capability to reduce the dependency on fossil fuels and carbon dioxide emissions. Renewable energy usually produces less carbon emissions during energy production than conventional fossil fuels do. However, the efficiency of renewable energy in reducing carbon dioxide emissions depends on the level of usage of renewable energy, existing energy systems, and the progress of the energy transition process in a particular nation. Various findings have been found for this relationship, whereby Pratama et al. (2021) have identified a considerable inverse relationship between renewable energy and CO₂ mitigation, either for long-term or short-term. He found a statistically significant long-term relationship between renewable energy consumption and CO₂ emissions by using a vector error correction model (VECM) in panel data analysis between 2007 and 2016. Therefore, it was concluded that an increase in renewable energy would reduce CO₂ emissions.

H3: Renewable Energy has a significant impact on CO₂ emissions

Relationship between Urbanisation and CO₂ Emissions

Urbanization is considered an important factor influencing the release of CO₂ emissions as far as energy demands, modes of transport, infrastructure, and consumption patterns are concerned. A study by Amiza and Jilil (2024) employs pooled OLS, fixed, and random effects panel approaches to explore the impact of urbanization on carbon emissions in seven ASEAN countries from 2011 to 2022. The authors conclude that urbanization positively affects carbon emissions together with economic growth. The findings have supported the previous study by Perwithosuci et al. (2023), which also found a positive connection between the urban population and carbon emissions in the ASEAN-5 in the period from 1990 to 2020 within a fixed-effects model. Most recent study by Thi and Thi (2025) analyze the influence of urbanization on carbon emissions through the lens of urbanization as a primary cause of carbon emissions based on the panel data of all ten ASEAN countries for 2000 to 2020 assert that continued urbanization in ASEAN countries is leading to increased environmental strain.

H4: Urbanization has a significant impact on CO₂ emissions

Relationship between Industrialization and CO₂ Emissions

Industrialization is the transformation of an economy from primarily agricultural to manufacturing and industrial production. It is this process that drives economic growth through productivity increases, job opportunities, and technical innovation. Susilowati et al. (2023) explore the relationship between industrialization and CO₂ emissions in ASEAN countries based on a Vector Error Correction Model (VECM) in the 2001–2020 period. They conclude that industrial value added has no statistically significant impact on CO₂ emissions in both short-run and long-run estimates. On the other hand, Claire and Widyawati (2023) found a positive coefficient of industrialization alongside a negative quadratic one (1.325 and –0.031) in their long-term findings on nine ASEAN member countries over the period of 1990–2019.

H5: Industrialization has a significant effect on CO₂ emissions.

3. Research Methodology

This research study aims to determine the factors influencing CO₂ emissions in Malaysia through a quantitative approach. A quantitative approach is appropriate in this case as numerical data is required in the form of time series data and as the study is likely to use various econometric techniques to analyze the relationships between CO₂ emissions and the independent variables.

Research Design

The effects on CO₂ emissions of economic growth, energy consumption, renewable energy consumption, urbanization, and industrialization are analyzed in this study. This study uses a time series research design covering the years between 1990 and 2023. Data for the analysis were obtained from reliable sources. These include the World Development Indicators (WDI) of the World Bank and the Asian Development Bank (ADB). The Autoregressive Distributed Lag (ARDL) model is used to determine the short-run and long-run relations among the variables. The ARDL model is applicable in this case since the variables can be integrated at different orders as long as at least one of the variables does not belong to the second order, I(2).

Table 1: Variable Measurement Table

Variables	Measurement	Unit	Source
CO ₂	CO ₂ emissions excluding land-use, land-use change and forestry (LULUCF)	Tonnes of CO ₂ equivalent per capita (t CO ₂ e/capita)	World Development Indicators (World Bank)
GDP	GDP per capita (constant 2015 US\$)	GDP per capita	World Development Indicators (World Bank)
EC	Energy use per capita	kg of oil equivalent per capita	World Development Indicators (World Bank)
RE	Renewable energy consumption as a share of total final energy consumption	% of total final energy consumption	World Development Indicators (World Bank) and Asian Development Bank
URB	Urban population as a percentage of total population	% of total population	World Development Indicators (World Bank)
IND	Industry value added (including construction)	% of GDP	World Development Indicators (World Bank)

Model Specification

An econometric model is constructed to determine the main independent variables affecting CO₂ emissions in Malaysia. The independent variables are economic growth, energy consumption, renewable energy consumption, urbanization, and industrialization. The model draws its theory from environmental economics. The model is expressed as follows:

$$CO_{2t} = f (GDP_t, EC_t, RE_t, URB_t, IND_t)$$

Where CO₂ emissions represent the dependent variable, while GDP, energy consumption, renewable energy consumption, urbanization and industrialization represent the explanatory variables.

The econometric techniques that have been used in this research include the unit root test to check whether the variables are stationary, and the ARDL model to determine the long-run relationship between the variables. The econometric models are as shown below:

$$CO_{2t} = \alpha_0 + \beta_1 GDP_t + \beta_2 EC_t + \beta_3 RE_t + \beta_4 URB_t + \beta_5 IND_t + \varepsilon_t \quad (1)$$

Where:

α_0 = constant term

$\beta_1 - \beta_5$ = Long-run coefficients of the explanatory variables

ε_t = Error term

CO_{2t} = Carbon dioxide emissions

GDP_t = Economic growth

EC_t = Energy consumption

RE_t = Renewable energy

URB_t = Urbanisation

IND_t = Industrialisation

To examine the existence of a long-run cointegrating relationship among the variables, the ARDL bounds testing approach is employed based on the Unrestricted Error Correction Model (UECM). The corresponding

bounds testing equation is specified as follows:

$$\Delta CO_{2t} = \alpha_0 + \sum_{i=1}^p \beta_i \Delta CO_{2,t-i} + \sum_{i=0}^{q1} \gamma_i \Delta GDP_{t-i} + \sum_{i=0}^{q2} \delta_i \Delta EC_{t-i} + \sum_{i=0}^{q3} \theta_i \Delta RE_{t-i} \quad (2)$$

$$+ \sum_{i=0}^{q4} \eta_i \Delta URB_{t-i} + \sum_{i=0}^{q5} \kappa_i \Delta IND_{t-i} + \phi_1 CO_{2,t-1} + \phi_2 GDP_{t-1}$$

$$+ \phi_3 EC_{t-1} + \phi_4 RE_{t-1} + \phi_5 URB_{t-1} + \phi_6 IND_{t-1} + \varepsilon_t$$

Where:

Δ = First difference operator representing short-run changes

$\phi_1, \phi_2, \dots, \phi_6$ = Long-run level coefficients used to conduct the ARDL bounds test

$p, q1, \dots, q5$ = Optimal lag lengths

ε_t = Error term

Additionally, various diagnostic tests will be done to check if the ARDL model is adequate and reliable. The Ramsey RESET test will check the appropriateness of the model specification, while the Jarque-Bera test will check if the residuals follow a normal distribution. The Breusch-Godfrey Serial Correlation LM test will check for serial correlation, and the Breusch-Pagan test will check if there are any remaining model residuals that are heteroskedastic. These tests are done to check if the estimated ARDL model fulfills the required assumptions of econometrics so that the results are reliable and robust.

4. Results & Discussion

This chapter presents the empirical results and discussion of the study examining the determinants of carbon dioxide (CO₂) emissions in Malaysia. The analysis comprises unit root tests, the Autoregressive Distributed Lag (ARDL) model, ARDL bounds testing for cointegration, and a series of diagnostic tests to assess the validity and robustness of the estimated model.

Table 2: Descriptive Statistics

Statistics	CO2	GDP	EC	RE	URB	IND
Mean	6.498144	2331.402	7749.933	47.21741	66.14024	41.8693
Median	7.019491	2301.691	7745.933	44.14001	66.34008	41.0670
Maximum	8.199600	3050.373	11445.39	68.30000	76.44348	48.5302
Minimum	3.612050	1188.841	4184.761	29.00000	49.03007	35.9347
Std. Dev.	1.422500	504.8371	2084.371	8.404584	8.331568	3.853371
Skewness	0.043214	0.004589	0.391170	0.848980	0.552982	0.081410
Kurtosis	1.909305	2.200833	1.915362	2.687282	2.107155	1.880700

Table 2 reports the descriptive statistics for CO₂ emissions, GDP, energy consumption, renewable energy consumption, urbanization, and industrialization in Malaysia. The descriptive statistics comprise the mean, median, maximum, minimum, standard deviation, skewness, kurtosis, and Jarque-Bera statistics. The mean indicates the average value of each variable over the study period, while the median represents the central value of the observations. The maximum and minimum values indicate the upper and lower bounds of each variable, respectively, providing an overview of the extent of variation and changes in the variables throughout the study period. The standard deviation further reflects the degree of dispersion of the observations around their respective means, while skewness and kurtosis provide information on the distributional characteristics of the data. The Jarque-Bera statistic is used to assess whether the variables follow a normal distribution.

The standard deviation shows that energy consumption is the one that exhibits more dispersion, whereas CO₂ emissions show less dispersion. This shows that there were more variations in energy consumption than in the other variables. The kurtosis gives the form and tail characteristics of a probability distribution. The value near 3 is typical for a normal distribution. However, in this case, the kurtosis figures are less than 3, lying between 1.8807 and 2.6873. As such, the variables are platykurtic, meaning they have distributions that are flatter than a normal distribution.

Table 3: Correlation

	CO2	GDP	EC	RE	URB	IND
CO2	1	0.8971	0.9832	-0.4230	0.9744	-0.3401
GDP	0.8971	1	0.9360	-0.0486	0.9515	-0.6063
EC	0.9832	0.9359	1	-0.3321	0.9817	-0.3790
RE	-0.4230	-0.0486	-0.3321	1	-0.3083	-0.3920
URB	0.9744	0.9515	0.9817	-0.3083	1	-0.4349
IND	-0.3401	-0.6063	-0.3790	-0.3920	-0.4349	1

The correlation analysis was conducted to assess the strength and direction of the linear relationships between CO₂ emissions and the selected independent variables. The results indicate that CO₂ emissions are strongly and positively correlated with energy consumption (EC), urbanization (URB), and GDP, with correlation coefficients of 0.9832, 0.9744, and 0.8971, respectively. These findings suggest that higher levels of energy consumption, urbanization, and economic growth are closely associated with higher CO₂ emissions in Malaysia.

In contrast, CO₂ emissions exhibit a moderate negative correlation with renewable energy consumption (RE), with a correlation coefficient of -0.4230, indicating that greater reliance on renewable energy is associated with lower CO₂ emissions. Meanwhile, industrialization (IND) shows a weak negative correlation with CO₂ emissions, with a coefficient of -0.3401. Overall, the correlation results provide preliminary evidence of the relationships between CO₂ emissions and the explanatory variables; however, these correlations should not be interpreted as evidence of causality.

Table 4: Unit Root Test

	Level I(0)		First Difference I(1)		Order of Integration
	Augmented Dickey-Fuller	Phillips-Perron	Augmented Dickey-Fuller	Phillips-Perron	
CO2	0.3153	0.2342	0.0000	0.0000	I(1)
GDP	0.9226	0.9549	0.0001	0.0000	I(1)
EC	0.2719	0.0537	0.0000	0.0000	I(1)
RE	0.7233	0.5547	0.0415	0.0442	I(1)
URB	0.3104	0.0000	0.4793	0.4793	I(0)
IND	0.7856	0.7728	0.0001	0.0001	I(1)

The Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests were employed to determine whether the data series are stationary or non-stationary. For both the ADF and PP tests, the null hypothesis assumes the presence of a unit root. If the p-value is less than 0.05, the null hypothesis is rejected, indicating that the variable is stationary. As presented in Table 4, the results reveal that CO₂, GDP, EC, RE, and IND are non-stationary at level but become stationary after first differencing. Therefore, all the mentioned series are I(1) variables. For CO₂ the ADF and PP tests at level produced probability values of 0.3153 and 0.2342, respectively, while at the first difference, the values were both 0.0000. The same way, for the GDP, the level p-values are 0.9226 and 0.9549 in the ADF and PP tests, respectively.

The probability values for EC in the ADF test and the PP test at level are 0.2719 and 0.0537, respectively, while those of the two tests became significant after first differencing at probability values of 0.0000. The RE is not stationary at level based on the ADF and PP p-values of 0.7233 and 0.5547, respectively, but became stationary after first differencing with p-values of 0.0415 and 0.0442, respectively. The IND follows a similar trend, where the level p-values are 0.7856 and 0.7728, respectively, and p-values of 0.0001 after first differencing.

However, the PP test shows stationarity of URB at level with a probability value of 0.0000. Thus, URB is considered an I(0) variable. Even though the ADF test at level gives a probability value of 0.3104, the PP test confirms the stationarity at the 5% level of significance. In summary, the outcome suggests that the variables consist of a mixture of I(0) and I(1) processes and do not include any I(2) process.

Table 5: ARDL

Variables	Coefficient	Std. Error	t-Statistic	Prob.
C	2.222632	1.948322	1.140793	0.2674
CO ₂ (-1)	0.003002	0.165010	0.018193	0.9857
GDP	0.000228	0.000121	1.892335	0.0730
GDP(-1)	-0.000310	0.000157	-1.981859	0.0614
GDP(-2)	-0.000160	0.000135	-1.186582	0.2493
EC	0.0001999	0.000354	5.642893	0.0000
EC(-1)	0.000875	0.000473	1.847563	0.0795
EC(-2)	0.000996	0.000366	2.723484	0.0131
RE	-0.019214	0.034020	-0.564779	0.5785
IND	0.014356	0.017250	0.832220	0.4151
URB	-0.846321	0.515096	-1.643034	0.1160
URB(-1)	0.805031	0.487965	1.649711	0.1146

The Autoregressive Distributed Lag (ARDL) model was used to examine the dynamic relationship between carbon dioxide (CO₂) emissions and its determinant factors such as Gross Domestic Product (GDP), energy consumption (EC), renewable energy consumption (RE), urbanization (URB), and industrialization (IND). The ARDL is suitable for this study, as the unit root results showed that there is a mixture of I(0) and I(1) variables, but no variables are integrated of order I(2). The estimation results from EViews suggest that the ARDL model selected contains the time lags of CO₂, GDP, EC, and URB. The coefficient of lagged CO₂, CO₂(-1), is 0.003002 with a probability value of 0.9857. This coefficient is statistically insignificant, which means that the impact of the previous period's CO₂ emission does not have a significant effect on the current CO₂ emission in the estimated model.

The current coefficient D(GDP), in the ARDL estimation, is represented by the coefficient of 0.000228 and the probability of 0.0730. The coefficient is positive, suggesting that an increase in GDP is associated with an increase in CO₂ emissions. The coefficient is not statistically significant at the 5% significance level, however. The first lag of GDP has a coefficient of -0.000310 with a probability value of 0.0614, while the second lag has a coefficient of -0.000160 with a probability value of 0.2493. Neither coefficient is statistically significant at the 5% level. This finding is consistent with the research by Ghoshray & Lorusso (2025), who found a positive correlation between GDP and CO₂ emissions in selected ASEAN economies such as Malaysia. It has been found that economic growth in the region is positively correlated with high CO₂ emissions due to increased energy consumption. However, the insignificance of income growth challenges the validity of the Environmental Kuznets Curve (EKC) hypothesis in Malaysia. The findings demonstrate that higher economic growth will not passively yield environmental recovery past a development threshold. Because economic development alone is insufficient to induce natural decarbonization, targeted policy interventions must focus on restructuring national energy demand, reforming fossil fuel subsidies, and accelerating clean-energy substitution to effectively decouple economic output from carbon emissions.

The current coefficient of energy consumption is 0.0001999, and the probability value is 0.0000, which shows that the coefficient is positive and statistically significant. This means that the higher the use of energy, the more CO₂ is emitted. The coefficient of the first lag of EC is 0.000875, and the probability value is 0.0795, which is not statistically significant at the 5% level. Meanwhile, the second lag of EC has a positive coefficient of 0.000996 and a probability value of 0.0131. Thus, there is a statistically significant positive association between the second lag of energy use and CO₂ emissions. The findings were supported by previous studies done by Saboori and Sulaiman (2013), which have shown a positive and significant relationship between energy use and CO₂ emissions in ASEAN countries. The study results showed that the higher the energy demand, the more emissions generated, especially in countries that are highly energy dependent on fossil fuel-based energy sources.

The coefficient of renewable energy consumption (RE) is -0.019214, and the probability value is 0.5785. The negative coefficient means that there is an inverse relationship between the use of renewable energy and CO₂ emissions. But this correlation is not statistically significant at the common 5% level of significance. So, the ARDL findings are not statistically significant enough to conclude that consumption of renewable energy has a significant impact on CO₂ emissions in the estimated model. This problem may be attributed to the current renewable energy contributions by Malaysia, which are still inadequate to achieve any significant decline in overall CO₂ emissions, considering the continued use of fossil fuels. This insignificant finding is in accordance with the findings of Nasution et al. (2026), who have used a Panel ARDL model for six ASEAN countries for the period 1990-2020 and found that consumption of renewable energy had a statistically insignificant effect on CO₂ emissions. The researchers argue that the present use of renewable energy in ASEAN countries may not be enough to produce any visible effect on CO₂ emissions.

Industrialization (IND) has a positive coefficient of 0.014356 with a probability value of 0.4151. The positive coefficient implies that increasing the level of industrialization might mean increasing CO₂ emissions, but this is not statistically significant at the 5% level. The insignificant result may be explained by the differences in Malaysia's industrial structure, technology, and source of energy, which can balance out the potential increase in emissions due to industrialization. These findings are consistent with those reported by Pratama et al. (2021), who found that industrialization in the ASEAN-5 nations failed to cause a statistically significant effect on CO₂ emissions. The authors suggest that the relationship between industrialization and CO₂ emissions might depend on the degree of industrialization and reliance on fossil fuels in the industry. The lack of significant results, however, indicates that there could be an environmental benefit to industrialization through better technology and cleaner production processes.

For the variable of Urbanization, the coefficient of the coefficient is negative, -0.846321 and the probability value is 0.1160. The negative coefficient indicates that the amount of CO₂ emissions could decrease with an increase in urbanization. But the coefficient is not statistically significant at the 5% level. This insignificant coefficient could be due to differences in the urbanization pattern, transportation facilities, and energy use in Malaysian cities that could neutralize the expected environmental impact of urbanization. The first lag of Urbanization has a positive coefficient of 0.805031 and has a probability value of 0.1146, which is not statistically significant. This result is consistent with the findings of Lubis & Widodo (2025), who found that the effect of urbanization on CO₂ emissions is not always positive and may vary based on different stages of urbanization development. This concept can explain the lack of significance noted in this paper.

Overall, the ARDL estimation results confirmed that energy consumption is positively related to CO₂ emissions, especially the second lag of energy consumption. In the reported ARDL estimation, the other explanatory variables fail to display any statistically significant effects at the 5% level. Next, the ARDL estimation result is followed by the Bounds Test to verify whether there is a long-run relationship between the variables.

Table 6: ARDL Bound Test

Test Statistic	Value	Significance	I(0)	I(1)
F-statistic	6.326279	10%	2.08	3
k	5	5%	2.39	3.38
		2.5%	2.7	3.73
		1%	3.06	4.15

To determine whether there is any long-run association between carbon dioxide emissions and the explanatory variables (GDP, EC, RE, URB, IND), an ARDL Bounds Test is used. The null hypothesis is that there is no long-run association among the variables. The test results show an F-statistic of 6.326279, where k = 5, representing the number of explanatory variables. The F-statistic obtained is compared against the lower bound I(0) and the upper bound I(1) at different significance levels.

Based on the confidence interval constructed using the 5% level of significance, the lower and upper bounds are 2.39 and 3.38, respectively. The F-statistic, which is 6.326279, is higher than the upper bound critical value of 3.38, thus leading to the rejection of the null hypothesis and suggesting the existence of a long-run relationship between the variables. Additionally, the F-statistics are greater than the upper bound critical

values at the 10%, 2.5%, and 1% levels of significance.

Table 7: Diagnostic Test

Diagnostic Test	F-Statistic	p-value
Breusch-Godfrey LM Test	2.940998	0.0836
Jarque-Bera Normality Test	0.352317	0.838485
Breusch-Pagan Test	1.023728	0.4730
Ramsey RESET Test	0.075798	0.7866

The results of the Breusch-Godfrey LM test were obtained with an F-statistic of 2.941 and a p-value of 0.0836. Considering that the p-value is greater than 0.05, it can be concluded that the null hypothesis of no serial correlation cannot be rejected. In other words, there is no serial correlation present in the model. The results of the Jarque-Bera test for normality show a statistic value of 0.352 and a p-value of 0.8384. The p-value being greater than 0.05 implies that we fail to reject the null hypothesis. This indicates that the data are normally distributed.

In the case of the Breusch Pagan test, the F-value is 1.023728, while the corresponding p-value is 0.4730. As the p-value is greater than 0.05, the null hypothesis is not rejected by the test, which means that heteroskedasticity is not present in the model. Likewise, the result of the Ramsey RESET test is as follows: the F-statistic equals 0.075798, while the p-value is 0.7866. Since the p-value is greater than 0.05, it means that the null hypothesis is not rejected. This indicates that there is no evidence of model misspecification.

5. Managerial Implications and Recommendations

There are many implications and recommendations to be taken from this study in relation to Malaysia's policymakers and other relevant stakeholders. The study highlights the need for synchronizing economic growth with energy usage and developing renewable energy alongside sustainable urban and industrial development. In the long term, energy consumption becomes the only significant variable affecting CO₂ emissions, while GDP, renewable energy consumption, industrialization, and urbanization are not found to be statistically significant. This shows that Malaysia must continue growing economically but work harder towards integrating low-carbon measures in its economic development process. More focus should be placed on green investment, energy efficiency, clean production, and renewable energy to ensure environmentally friendly economic growth.

Based on the ARDL estimation results, energy consumption is identified as the most significant determinant influencing CO₂ emissions in Malaysia. The positive correlation and statistical significance between energy consumption and CO₂ emissions show that energy consumption plays an important role in CO₂ emissions in Malaysia. Therefore, Malaysia must continue working towards improving the implementation of energy efficiency policies at the household, transport, commercial, and industrial levels. Efforts should be made to encourage the use of energy-efficient technologies and improve energy efficiency, especially in energy-intensive industries. Incentives may also be considered to encourage firms to lower their energy intensities and use energy-efficient technologies. Moreover, there might be some consideration by the government on the amendment of existing fossil fuel subsidy structures to act as an additional way to control energy demand and encourage efficient energy consumption. This is in line with Yahoo et al. (2024)'s assertion on the need for clean energy growth and subsidies for energy to be integrated in order to help Malaysia achieve its CO₂ emissions targets. Overall, all these actions can help in reducing energy consumption in Malaysia.

Despite the negative coefficient of renewable energy consumption, its effect in the model is statistically insignificant. Therefore, although renewable energy has the potential to reduce CO₂ emissions, stronger implementation and wider adoption are required before its environmental impact becomes significant. This suggests that the present level of renewable energy usage is not enough to make a statistically significant change in CO₂ emissions. This concurs with Nasution et al. (2026), whose position is that current uses of renewable energy might not be enough to produce any effects on CO₂ emissions. Therefore, Malaysia must continue to enhance and develop renewable energy programs. There needs to be more attention paid to accessibility, involvement, investment, and efficiency of the present renewable energy programs. Moreover,

there must always be monitoring done in order to see how much renewable energy contributes to CO₂ reduction.

Urbanization is found to have a negative but statistically insignificant relationship with CO₂ emission levels. Therefore, the obtained findings cannot provide statistical evidence regarding the reduction of CO₂ emissions as a result of urbanization in Malaysia. The finding corresponds to those of Lubis & Widodo (2025), which state that the effect of urbanization on CO₂ emissions depends on the level of urbanization development. The implication is that the environmental impact of urbanization can be determined by such factors as urbanization development pattern, transportation system, and energy consumption. In this regard, Malaysia needs to continue implementing sustainable urbanization in terms of sustainable public transport, buildings, and urbanization planning.

Industrialization shows a positive but insignificant relationship with CO₂ emissions. Even though the relationship between industrialization and CO₂ emissions is not statistically significant, the positive coefficient indicates the possibility of some pressure on the environment arising from the process of industrialization. Taking into account that the influence of the process under consideration could differ depending on the industrial structure, the type of technology used, and energy sources, it is important for Malaysia to encourage the use of clean production, efficient technologies, and renewable energy in industries.

Conclusion

This research attempts to identify the determinants of CO₂ emissions in Malaysia using the ARDL methodology in order to examine the impacts of GDP, energy consumption, renewable energy consumption, urbanization, and industrialization. The findings indicate that there exists a long-run relationship between the variables considered in the research, suggesting that the selected factors are relevant in explaining CO₂ emissions in Malaysia.

The findings identify GDP and energy consumption as significant determinants of CO₂ emissions. The GDP is positively and significantly effect on CO₂ emissions in the long run, while the energy consumption is also positively and significantly related to the CO₂ emissions. Renewable energy consumption is negatively but statistically insignificant in its relation to CO₂ emissions. Urbanization is negatively and statistically insignificant, while industrialization is positively but statistically insignificant in relation to CO₂ emissions.

In general, the study results indicate the importance of regulating energy usage and sustainable economic growth as key elements for solving the problem of CO₂ emissions in Malaysia. The study provides empirical support useful for the decision-making process in developing solutions to help Malaysia achieve its goals towards becoming a low-carbon economy. At the same time, the results obtained may act as an example for future studies to analyze CO₂ emissions in Malaysia using different variables, methods, and time frames. In this way, there is a possibility to get a more comprehensive picture of the main drivers of CO₂ emissions in Malaysia.

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