DETERMINANTS OF CO2 EMISSIONS IN MALAYSIA: AN EKC ANALYSIS

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Abstract. CO_2 emissions remain a major challenge to Malaysia's sustainable development and transition toward a green economy. This study examines the determinants of CO_2 emissions in Malaysia from 1990–2024, focusing on GDP, energy consumption, and trade (imports and exports of goods and services). Guided by the Environmental Kuznets Curve (EKC) framework, the study investigates the long-run effects of these variables on environmental quality. Using annual data from the World Bank and econometric techniques including the Augmented Dickey-Fuller (ADF) unit root test, Akaike Information Criterion (AIC), cointegration, and regression analyses, the findings show that GDP, energy consumption, and imports significantly increase CO_2 emissions, supporting the inverted U-shaped EKC hypothesis. Exports exhibit mixed effects, with stronger impacts at higher emission levels, while energy consumption acts as a key channel through which trade influences environmental degradation. The results highlight the need for green economy strategies that promote energy efficiency and sustainable trade practices to decouple economic growth from environmental degradation. Despite being limited to data available up to 2024, the study provides valuable evidence for policymakers seeking to align Malaysia's economic and trade objectives with international carbon reduction commitments.
Keywords: *CO_2 emissions, EKC, GDP, energy consumption, imports, exports*

Introduction

Sustainable development is closely linked to reducing CO_2 emissions. In line with international commitments such as the Kyoto Protocol and UNFCCC, Malaysia has adopted the UN Sustainable Development Goals and aims to reduce carbon emission intensity per unit of GDP by 45% by 2030 (Abdul-Aziz, 2023). However, rapid industrialization since the 1990s has increased economic growth alongside fossil fuel dependence, with non-renewable sources still accounting for over 90% of the national energy mix. Within ASEAN, Malaysia's environmental challenges are driven by the interaction between economic growth, energy consumption, and trade. A 1% increase in GDP is associated with a 0.9% rise in CO_2 emissions, while energy consumption has increased by more than 50% over the past two decades. Furthermore, export-oriented industries such as palm oil and electronics contribute significantly to the country's carbon footprint. Although policies such as the National Renewable Energy Policy target a 20% renewable energy share by 2025, economic growth remains a dominant driver of emissions. Therefore, examining these relationships is crucial for balancing

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Malaysia's economic development and environmental sustainability. *Figure 1* shows that Malaysia's per capita CO_2 emissions generally increased between 1976 and 2024.

This study examines the determinants of CO_2 emissions in Malaysia during its transition toward a green economy from 1990 to 2024. Specifically, it investigates the effects of Gross Domestic Product (GDP), energy consumption, imports, and exports on carbon emissions. Using 150 observations from the World Bank, the study applies the Autoregressive Distributed Lag (ARDL) approach to analyze long-run relationships among these variables. Unlike studies that use net exports, imports and exports are examined separately to provide a clearer understanding of their individual impacts on environmental quality. The study contributes to the literature by assessing the Environmental Kuznets Curve (EKC) hypothesis in the Malaysian context. The findings offer valuable insights into the relationship between economic growth, trade, energy use, and environmental sustainability. By highlighting the environmental implications of continued economic expansion and fossil fuel dependence, the study provides evidence to support policy formulation, sustainable investment decisions, and Malaysia's commitment to achieving long-term sustainable development goals.

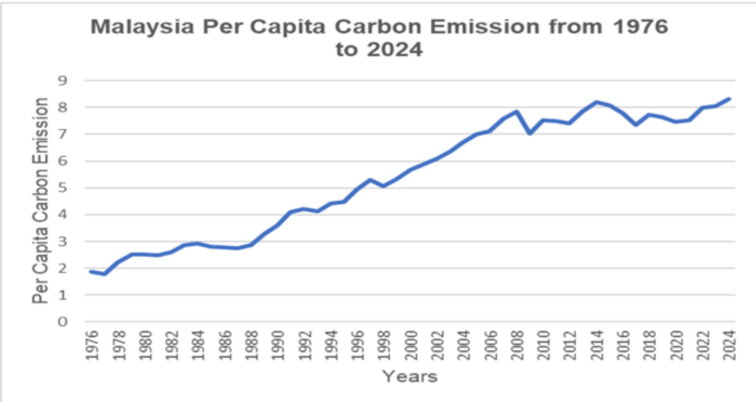

Figure 1. *Malaysia per capita carbon emission.*
Source: World Development Indicator (WDI).

Literature review

This literature review synthesizes scholarly perspectives on the dynamic interplay between CO2 emissions and key macroeconomic determinants—specifically Gross Domestic Product (GDP), energy consumption, and trade flows. By drawing on both global and regional studies, this section contextualizes Malaysia's transition toward a green economy, highlighting the empirical patterns and theoretical gaps that necessitate the use of advanced econometric frameworks like the Autoregressive Distributed Lag (ARDL) model to capture long-run causal linkages. The Environmental Kuznets Curve (EKC) hypothesis forms the basis of this study, proposing an inverted U-shaped relationship between economic growth and environmental degradation. In the early stages of development, pollution rises with income, but beyond a certain threshold, cleaner technologies and stronger environmental regulations contribute to lower emissions. The EKC is often linked to the Pollution Haven Hypothesis, which suggests that developed countries may reduce domestic emissions by relocating pollution-intensive industries to developing economies. Together, these theories provide a

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framework for assessing whether Malaysia's economic growth is environmentally sustainable.

Previous studies report mixed evidence on the relationships among CO_2 emissions, economic growth, energy consumption, and trade. Balsalobre-Lorente et al. (2023) found that renewable energy reduces CO_2 emissions in five European countries, while Chen et al. (2019) reported a similar negative relationship in South Korea. In Malaysia, studies by Raihan et.al (2022), Ridzuan and Ismail (2022) as well as Sharif et.al (2020) employed the ARDL approach and found that GDP, trade, energy consumption, and renewable energy significantly influence CO_2 emissions, supporting the EKC hypothesis. Other studies have shown that imports and exports also affect carbon emissions, particularly in developing economies (Aghasafari et al., 2021). Despite extensive research, important gaps remain. Most Malaysian studies rely on mean-based estimation techniques that may overlook variations across emission levels. In addition, limited attention has been given to the distinct roles of imports and exports and the mediating effects of energy consumption. Addressing these gaps, this study provides a more comprehensive assessment of the determinants of CO_2 emissions and contributes to evidence-based policies supporting Malaysia's green economy transition.

Materials and Methods

Data sources

The empirical analysis employs annual secondary data from 1990 to 2024, sourced from the World Bank's World Development Indicators (WDI) database. To mitigate heteroscedasticity and standardize variables measured in different units, all data were transformed into natural logarithms. This transformation enables the estimated coefficients to be interpreted as elasticities, facilitating a more robust analysis of the relationships among the determinants of carbon emissions.

Variable definition and measurement

Table 1 summarizes the determinants of CO_2 emissions in Malaysia and their measurements. Guided by the Environmental Kuznets Curve (EKC) framework and existing empirical literature, the analysis explores the relationship between CO_2 emission and its determinants.

Table 1*. Summary of variables definition and measurement.*

Variable	Measurement	Expected sign	Justification
Gross Domestic Product (GDP)	C + G +I+NX	+/-	Measures the total value of goods and services produced in a country over a given period.
Energy Consumption (EC)	Total supply (transformation input+ transformation output)	+/-	Measures final energy consumption, which excludes energy transformation losses
Import of Goods and services (IM)	Total value of goods brought into a country from abroad	+/-	Measure product or service produced abroad and purchased domestically
Export of Goods and services (EX)	Total value of goods sold to foreign countries	+/-	Measure good or service produced in one country and sold in another

Econometric analysis

The first step in the analysis is the correlation matrix, which presents the strength and direction of linear relationships among variables using Pearson's correlation coefficient (r), ranging from -1 to +1. Next this paper will use the unit root test. We used the case with a constant and no trend, as preliminary tests indicated no significant deterministic

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trend in the data. This justifies the use of the corresponding critical values for the bounds test. Additionally, the study adopted the Augmented Dickey and Fuller (1979). The ADF model used in this research for the unit root test has the following Eq. (1).

$$\Delta Yt = \mu + \beta t + \alpha Yt\text{-}1 + + \; + \Delta Yt\text{-}1 + \mu \qquad \text{Eq. (1)}$$

In ARDL, serial correlation can cause bias results, thus testing and adjusting lags accordingly is logical and best practice. The ARDL bounds test for cointegration is conducted to examine the long-run relationship among the variables. The test is based on the F-statistic, which tests the null hypothesis of no cointegration. For bound cointegration test, the unrestricted error correction model (UECM) of the ARDL model is expressed as follows. ARDL Bound Cointegration Model

$$\Delta \ln CMt = \alpha 0 + \alpha 1 \ln GDPMt\text{-}1 + \alpha 2 \ln IMMt\text{-}1 + \alpha 3 \ln EXPMt\text{-}1 + \alpha 4 \ln ECMt\text{-}1 + i \; \Delta \ln CMt\text{-}i \;\; j \; \Delta \ln GDPMt\text{-}j + \; g \; \Delta \ln IMMt\text{-}g + \; s \; \Delta \ln EXPMt\text{-}s + \; w \; \Delta \ln ECMt\text{-}w + \mu \qquad \text{Eq. (2)}$$

The unrestricted error correction model (UECM) of the ARDL model Eq. (2) is for Malaysia. In these equations, the long-run coefficients θj, θi, θg, θs, θw, and θx. Additionally, the short-run coefficients (α1 – α6). In this study the Wald-test was employed in order to perform the joint test hypothesis as follows. Wald-test for Malaysia's ARDL Bound Cointegration Test

$H0: \alpha 1 = \alpha 2 = \alpha 3 = \alpha 4 = \alpha 5 = \alpha 6 = 0$
$H1: \alpha 1 = \alpha 2 = \alpha 3 = \alpha 4 = \alpha 5 = \alpha 6 \neq 0$

Under the Wald test procedure, the F-statistic obtained from the estimated model is compared to the critical F-statistic values. After the variables cointegration was obtained, the next stage is the development of the long-term estimation model for Malaysia as follows:

$$\ln CMt = \alpha 0 + \alpha 1 \ln GDPMt\text{-}1 + \alpha 2 \ln IMMt\text{-}1 + \alpha 3 \ln EXPMt\text{-}1 + \alpha 4 \ln ECMt\text{-}1 + i \; \Delta \ln CMt\text{-}i \;\; j \; \Delta \ln GDPMt\text{-}j + \; g \; \Delta \ln IMMt\text{-}g + \; s \; \Delta \ln EXPMt\text{-}s + \; w \; \Delta \ln ECMt\text{-}w + \mu \qquad \text{Eq. (3)}$$

Next, the short-term coefficients were calculated by employing the error correction (ECM) in accordance with the ARDL model. The ARDL short-run estimation model for Malaysia is:

$$\ln CMt = \alpha 0 + \alpha 1 \ln GDPMt\text{-}1 + \alpha 2 \ln IMMt\text{-}1 + \alpha 3 \ln EXPMt\text{-}1 + \alpha 4 \ln ECMt\text{-}1 + i \; \Delta \ln CMt\text{-}i \;\; {}_{k} \Delta \ln GDPMt\text{-}k + \; h \; \Delta \ln IMMt\text{-}h + \; s \; \Delta \ln EXPMt\text{-}s + \; e \; \Delta \ln ECMt\text{-}e + \mu \qquad \text{Eq. (4)}$$

Referring to these equations, the notations and (4) denote the error correction terms magnitude values for Malaysia respectively. This magnitude measures the speed of adjustment of the system equation. In other words, they illustrate the time taken for short-run shocks to adjust from short run disequilibrium to long-run equilibrium. The ECTMt-1 denote the lagged error correction terms, for Malaysia.

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Results and Discussion

Correlation matrix

Table 2 presents the correlation matrix, which indicates strong positive relationships among the logged variables: $\ln CO_2$ (natural logarithm of CO_2 emissions), lnGDP (gross domestic product), lnEC (energy consumption), lnIM (imports), and lnEX (exports). All pairwise correlation coefficients range from 0.57 to 0.96, suggesting that increases in one variable are generally associated with increases in others, reflecting the interdependence between economic activity, trade, energy use, and environmental outcomes.

Table 2. *Results of correlation matrix.*

Category	lnCO2	lnGDP	lnEC	lnIM	lnEX
lnCO2	1.0000	0.8987	0.8464	0.7112	0.791126
lnGDP	0.8987	1.0000	0.9632	0.6096	0.753621
lnEC	0.8464	0.9632	1.0000	0.5699	0.644043
lnIM	0.7112	0.6096	0.5699	1.0000	0.881818
lnEX	0.791126	0.753621	0.644043	0.881818	1.0000

Augmented Dickey Fuller Unit Root Test

As emphasized by Karim et al (2017) the variables must not be integrated of order two, I(2), to ensure the validity of subsequent econometric analysis. To assess stationarity, this study employs the Augmented Dickey–Fuller test. *Table 3* reports the unit root test results for all variables in both level and first-difference forms. The findings indicate that all series are non-stationary in levels, as the null hypothesis of a unit root cannot be rejected, implying that the variables are not integrated of order zero, I(0). This suggests the presence of stochastic trends or common underlying stochastic components. However, upon first differencing, the null hypothesis of non-stationarity is rejected at the 1% significance level (as reported in Table 3), confirming that all variables become stationary. Hence, the series are integrated of order one, I(1), satisfying the prerequisite for further cointegration analysis.

Table 3. *Augmented Dickey Fuller Unit Root Tests Results.*

Data Series	Level Form			First Difference Form		
	Pure (None)	Without Trend	With Trend	Pure (None)	Without Trend	With Trend
CO2	-3.718042	-2.809259	-1.854380	-3.503001	- 6.419922	-6.886368
	(0.5452)	(0.0675)	(0.6557)	(0.0567)	(0.0000)	(0.0000)
GDP	7.835403	-2.415429	-1.789773	-6.104573	-6.104573	-6.958085
	(1.0000)	(0.1452)	(0.6875)	(0.0000)	(0.0000)	(0.0000)
EC	0.651519	-4.030539	-1.662068	-1.597642	-7.410365	-3.598457
	(0.8512)	(0.0039)	(0.7446)	(0.0024)	(0.0000)	(0.0117)
IM	0.666277	-3.403753	-6.011559	-8.564344	-5.527444	-8.512389
	(0.8550)	(0.0178)	(0.0001)	(0.0000)	(0.0051)	(0.0000)
EX	0.914300	-0.881694	-4.947379	-10.80717	-10.81716	-10.71923
	(0.8998)	(0.7814)	(0.0017)	(0.0000)	(0.0000)	(0.0000)

Optimum lag-length selection

This study adopts the Akaike Selection Criteria (AIC) in order to select the optimum lag for the model development. *Table 4* simplifies the lag optimum proposed by AIC. Iterative testing up to lag 4 showed that increasing the lag order to 4 resolved the autocorrelation issue, with an AIC value of -13.05688, outperforming the other lags such as lag 1 at -12.38589, lag 2 at -12.42715, and lag 3 at -12.27693). This demonstrates effective model refinement through lag adjustment.

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***Table 4**. The selection of optimum lag-length by AIC.*

Lag Length	Akaike Information Criterion (AIC)
1	-12.38589
2	-12.42715
3	-12.27693
4	-13.05688*

ARDL bound cointegration

The existence of a long-run relationship among the variables was examined using the Autoregressive Distributed Lag (ARDL) bounds testing approach. The computed F-statistic for Malaysia is 6.077, which is evaluated against the critical value bounds reported by Narayan (2005) at the 5% significance level. The corresponding lower and upper bound critical values are 3.47 and 4.57, respectively. *Table 5* shows results from the linear ARDL bounds cointegration test provide clear evidence of a long-run relationship among the variables. The computed F-statistics for Malaysia (6.077025) exceeds the critical upper bound value of 4.57 at the 5% significance level, based on Narayan (2005), where the lower and upper bounds are 3.47 and 4.57, respectively. As the F-statistic is higher than the upper bound, the null hypothesis of no cointegration is rejected, confirming the existence of cointegration among CO_2 emissions, Gross Domestic Product (GDP), energy consumption (EC), imports (IM), and exports (EXP). This indicates that these variables move together in the long run and maintain an equilibrium relationship. The presence of cointegration implies that any short-term deviations from equilibrium are temporary, as the variables adjust over time to restore long-run stability. In practical terms, shocks to one variable—such as changes in GDP or energy consumption—will have lasting effects on CO_2 emissions rather than causing divergence. This finding justifies proceeding with the full ARDL model estimation, including both long-run coefficients and the short-run error correction mechanism (ECT). Overall, the results suggest that CO_2 emissions in Malaysia are closely linked to economic activity, with GDP and energy consumption likely exerting upward pressure on emissions over the long term.

***Table 5**. ARDL bound cointegration test results.*

Test Statistics	Value	Significance level	Bound critical values	
			I(0)	I(1)
F-statistics	6.077025	1.0%	3.03	4.06
		5.0%	3.47	4.57
		2.5%	3.89	5.07
		10.0%	4.4	5.72

ARDL short-run model

The short-run ARDL results indicate a good model fit and strong explanatory power. As shown in *Table 6*, the coefficient of determination (R^2 = 0.8218) suggests that approximately 82% of the variation in CO_2 emissions is explained by the included regressors, while the adjusted R^2 (0.6855) confirms that the model remains robust after accounting for model complexity. The overall model is statistically significant, as evidenced by the F-statistic of 6.031 (p = 0.000421), indicating that the explanatory variables are jointly significant. Furthermore, the Durbin–Watson statistic of 2.454 suggests no serious autocorrelation problem, supporting the reliability of the estimates. The information criteria values (AIC = 0.2644, SC = 0.9120, HQ = 0.4755) also indicate a reasonably well-specified and parsimonious model. Overall, the ARDL short-run

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results provide a robust representation of the relationship between CO_2 emissions, economic growth, energy consumption, and imports in Malaysia. The model is statistically significant, as indicated by the F-statistic of 6.031 ($p = 0.000421$), leading to the rejection of the null hypothesis that all coefficients are jointly equal to zero. The Durbin–Watson statistic of 2.454 suggests the absence of serious autocorrelation, supporting the reliability of the estimates. In addition, the information criteria (AIC = 0.2644, SC = 0.9120, HQ = 0.4755) indicate a reasonably well-specified and parsimonious model, although further validation using alternative lag structures may be beneficial.

Table 6*. ARDL short-run model.*

Category	Coefficient	t-Statistics
C	-337.1233	-6.302771
lnGDP	1.500889	1.260112
lnEC	1.421933	1.075714
lnIM	1.206727	6.335350
CointEq(-1)	-2.378290	-6.303522
R-squared	0.821808	
Adjusted R-squared	0.685544	
F-statistics	6.030994***	
Durbin-Watson	2.453970	
Akaike	0.264416	
Schwarz criterion	0.912023	
Hannan-Quinn criteria	0.475519	

*Note: ***1% level of Significance.*

The short-run estimates show varying elasticities across the explanatory variables. The constant term is statistically significant ($t = -6.303$), reflecting a baseline adjustment in CO_2 emissions that may be associated with structural or policy-related factors. Meanwhile, lnGDP (1.5009; $t = 1.2601$) and lnEC (1.4219; $t = 1.0757$) exhibit positive but statistically insignificant coefficients, suggesting that short-run changes in economic growth and energy consumption do not have a significant immediate effect on CO_2 emissions. In contrast, lnIM (1.2067; $t = 6.3354$) is positive and highly significant, indicating that a 1% increase in imports leads to an estimated 1.21% rise in CO_2 emissions. This finding underscores the contribution of trade-related activities to environmental degradation through the importation of carbon-intensive goods. The error correction term, CointEq(−1), is negative and highly significant (−2.3783; $t = -6.3035$), confirming the existence of a long-run equilibrium relationship. However, its relatively large magnitude suggests a rapid adjustment process that may involve overshooting, and therefore should be interpreted with caution. Overall, the results indicate that import activity is the main short-run driver of CO_2 emissions in Malaysia, whereas economic growth and energy consumption have limited immediate effects. The significant error correction mechanism further demonstrates the model's stability and convergence toward long-run equilibrium, although the insignificance of certain coefficients and the high adjustment speed warrant careful interpretation. To assess the significance of individual coefficients in the ARDL error correction model (ECM), t-tests are employed. The null hypothesis (H_0) assumes that a coefficient is equal to zero, indicating no effect, while the alternative hypothesis (H_1) assumes a non-zero coefficient, indicating a significant effect. At the 5% significance level, the null hypothesis is rejected when the absolute t-statistic exceeds approximately 1.96 in a two-tailed test, assuming a large sample and normal distribution.

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ARDL long-run model

The ARDL long-run results in *Table 7* confirm a stable equilibrium relationship between CO_2 emissions and the selected economic variables. The model demonstrates excellent explanatory power, with an R^2 of 0.986 and an adjusted R^2 of 0.980. The overall model is highly significant (F-statistic = 155.241, $p < 0.001$), while the Durbin–Watson statistic (2.090) indicates no residual autocorrelation. The information criteria values (AIC = −3.861, SC = −3.362, HQ = −3.693) further support the model's parsimony. Regarding the long-run coefficients, GDP (lnGDP) has a positive and significant effect on CO_2 emissions (0.445; t = 3.953), indicating that a 1% increase in GDP raises emissions by approximately 0.44%. Similarly, imports (lnIM) positively and significantly influence CO_2 emissions (0.416; t = 2.130), suggesting that trade-related activities contribute to environmental pressure in Malaysia. On the other hand, exports (lnEXP) display a significant negative coefficient (−0.642; t = −2.731), indicating that increased export activity may reduce emissions, possibly reflecting a shift toward cleaner or more efficient export-oriented sectors. Energy consumption (lnEC), however, is not statistically significant (0.014; t = 0.276), suggesting a limited long-run impact, potentially due to energy efficiency gains or structural changes in energy use. Collectively, the findings indicate that Malaysia's long-run CO_2 emissions are primarily driven by economic growth and imports, while exports play a mitigating role, and energy consumption appears to have a negligible long-run effect. This contrasts with short-run dynamics, where the influence of GDP is weaker and imports tend to dominate.

***Table 7**. ARDL long-run model.*

Category	Coefficient	t-Statistics
C	4.004391	1.028978
lnGDP	0.444738	3.953011
lnEC	0.014491	0.276339
lnIM	0.415627	2.130183
CointEq(-1)	-0.641901	-2.731266
R-squared	0.986027	
Adjusted R-squared	0.979675	
F-statistics	155.2414***	
Durbin-Watson	2.089626	
Akaike	-3.861045	
Schwarz criterion	-3.362209	
Hannan-Quinn criteria	-3.693202	

*Note: ***1% level of significance.*

Conclusion

The findings reveal that economic growth, energy consumption, and imports significantly contribute to CO_2 emissions in Malaysia, with energy consumption emerging as the primary driver of environmental degradation. The positive relationship between GDP and emissions suggests that Malaysia remains in the upward phase of the Environmental Kuznets Curve (EKC), where economic expansion continues to be closely linked to environmental pressures. These results highlight the urgent need to decouple economic growth from carbon emissions through greater adoption of renewable energy, green technologies, and sustainable trade practices. Malaysia's transition toward a low-carbon economy will require stronger environmental governance, responsible industrial development, and enhanced regional cooperation.

Beyond economic and technological solutions, long-term sustainability depends on cultivating environmental awareness, ethical responsibility, and active public participation. Ultimately, achieving sustainable development will require balancing economic prosperity with environmental stewardship to ensure a cleaner and more resilient future for generations to come.

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Conflict of interest

The authors confirm that there is no conflict of interest involve with any parties in this research study.

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