

Land Use, CO₂ Emissions, and Economic Growth in Malaysia

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Abstract

This study investigates the effects of land use, carbon dioxide (CO₂) emissions and population growth on economic growth in Malaysia from 1990 to 2023. For each year, time-series data were collected from the World Development Indicators (WDI) and CEIC Data. We used unit root tests to examine the stationarity properties of the variables: Augmented Dickey-Fuller (ADF), Dickey-Fuller Generalized Least Squares (DF-GLS) and Kwiatkowski-Phillips-Schmidt-Shin (KPSS). The Autoregressive Distributed Lag (ARDL) bounds testing approach and the Error Correction Model (ECM) were used to examine the relationships among variables in the long and short run. The results validate a stable relationship between real GDP per capita, population growth, land use and CO₂ emissions. The long-term projections show that population growth has a negative and significant impact on real GDP per capita, while land use and CO₂ emissions have a positive but statistically insignificant impact. The short-term results show positive effects of population growth at some of the lag periods and significant negative effects of land use and CO₂ emissions at some of the lag intervals, while the immediate effects are not significant. The error correction term is negative and statistically significant, providing further evidence for the convergence to the long-run equilibrium. The results emphasize the significance of differentiating between short- and long-term effects of demographic and environmental factors on the economic performance of Malaysia. The study calls for the implementation of policies that enhance labor productivity, sustainable land management, resource efficiency and low-carbon development to facilitate long-term economic growth in Malaysia.

Keywords: Land Use, Carbon Dioxide Emissions, Economic Growth, Population Growth, Malaysia

Introduction

Economic growth continues to be a key goal for developing countries, as it results in income generation, job creation, and improved living standards (Dragoi, 2020). However, economic development is often linked to increased pressure on natural resources and environmental quality, particularly through industrialization, urbanization, agricultural expansion and

infrastructure development. Such activities could change land-use patterns, increase energy consumption and lead to carbon dioxide (CO₂) emissions and environmental degradation. Land allocation changes may also affect economic performance through their implications for agricultural production, industrial development and utilization of resources. Thus, the link between economic growth and environmental sustainability has become a major concern for developing countries like Malaysia, where continuous economic growth has to be in line with the sustainable management of land resources and environmental quality.

Malaysia is a relevant context to explore the relationships between land-use patterns, CO₂ emissions, population growth and economic performance. In 1990, arable land accounted for 2.83% of the total land area in Malaysia, which decreased to 2.39% in 2023 (World Bank, 2025). During the same period, the per-capita CO₂ emissions excluding land use, land-use change and forestry (LULUCF) increased from 3.61 to 8.04 tons, but the real GDP per capita rose significantly. These trends reflect changes in the availability of agricultural land and environmental pressures as well as Malaysia's economic growth. The agricultural dimension of land-use patterns in this study is represented by arable land as a percentage of total land area. Arable land is defined as the land under temporary crops, temporary meadows, market and kitchen gardens, and land temporarily fallow according to the World Bank (2025). This indicator is relevant as it captures the share of land used for arable agricultural activities, which can be related to agricultural production, allocation of resources and economic performance. Moreover, the data availability over the study period provides a consistent basis for the research on long-term changes in arable land share. However, arable land only represents one aspect of land use, not directly including urbanization, industrial land conversion, deforestation or changes in land-cover quality. So, the indicator is viewed as a description of agricultural land-use patterns, not a complete picture of land-use transformation.

The link between economic growth and environmental degradation has been extensively discussed under the hypothesis of the Environmental Kuznets Curve (EKC) (Grossman & Krueger, 1991). According to the EKC hypothesis, environmental degradation increases with economic development at first, but may decrease after a certain level of income, as technological improvements, structural changes in the economy and environmental regulations become more important. The present study does not directly test the EKC hypothesis, but provides a relevant theoretical background for the analysis of the relation between economic activity and environmental pressures. In economics, land resources are an input into productive activity, and changes in the use of land can affect economic efficiency and the use of resources. Similarly, CO₂ emissions could be a proxy for environmental pressures from industrial production, energy consumption, and transportation. Population growth is another dimension; demographic changes may influence labor supply, consumption, resource demand and economic performance. Hence, integrated analysis of these factors may yield a more comprehensive understanding of the interconnections between environmental conditions, agricultural land resources, demographic changes and economic performance.

The relationship between land use change and CO₂ emissions, population growth, and economic performance has been examined in previous empirical studies, with inconsistent findings across geographical contexts and methodological approaches. Much research on land-use dynamics has been directed at the economic impacts of the expansion of urban areas

and land allocation. Deng et al. (2010) and He et al. (2014) reported that in China, economic development was closely linked to urban land expansion and the conversion of agricultural land to urban and industrial uses. In the same vein, Chen et al. (2020) showed significant relationships among land-use and land-cover changes and regional economic development. Lin et al. (2023) also pointed out that inefficient land allocation would negatively impact economic performance. However, the results of the studies on the nexus between CO₂ emissions and economic growth are mixed. The studies of Rahman et al. (2020) and Balsalobre-Lorente and Leitão (2020) have found a positive association between CO₂ emissions and economic growth, while Abbasi et al. (2021) found a negative association. Androniceanu and Georgescu (2023) also show that the relationship may differ in the short and long run. Research on population growth has yielded mixed results; a positive relationship has been reported by Furuoka (2009) and Rahman et al. (2017), whereas Abdullah et al. (2015) found a negative relationship. These results suggest that the relationships between environmental, demographic and economic variables may be conditional on the economic structure, the distribution of resources and the period of analysis. Much of the land use evidence that we reviewed, however, is from China, while the studies on CO₂ emissions and population growth have largely examined different sets of countries and economic contexts. Hence, the relationship between agricultural land resources, CO₂ emissions, population growth and the overall economic performance warrants further study in the Malaysian context.

Against these circumstances, the present study examines the nexus between arable land, CO₂ emissions, population growth and real GDP per capita in Malaysia using annual time series data over the period 1990-2023. The present study aims to contribute to the existing literature by incorporating three different but economically relevant dimensions into a single empirical framework: agricultural land resources, proxied by arable land as a percentage of total land area; environmental pressures of economic activity, proxied by CO₂ emissions per capita; and demographic changes, proxied by annual population growth. Earlier studies have offered useful evidence on land-use dynamics, emissions and demographic factors, but the literature reviewed offers comparatively limited Malaysia-specific evidence on their joint relationships with real GDP per capita. Combining these variables into one model enables the assessment of their relationship with economic performance while controlling for other included variables. The Autoregressive Distributed Lag (ARDL) approach is used to examine the short-run dynamics and long-run relationship among the variables. This is especially relevant in light of contrasting short-run and long-run results in previous studies. The contribution of the present study is not in bringing out a new econometric methodology. The contribution is in providing an integrated, country-specific empirical assessment of agricultural land resources, environmental pressures and demographic changes in relation to Malaysia's economic performance. The results are expected to provide useful insights for sustainable agricultural land management, environmental policy, and long-term economic development.

The rest of the paper is organized as follows. Section 2 reviews the relevant empirical literature on land-use change, CO₂ emissions, population growth and economic growth. The data, empirical model and methodology are presented in Section 3. Section 4 presents and discusses the empirical results, and Section 5 concludes the paper and discusses the relevant policy implications.

Literature Review

The body of research regarding land-use modification, carbon dioxide emissions, population growth, and economic progress can be broadly divided into three categories. First, we analyze the relationship between changes in land utilization and economic growth. In the next case, we analyze the relationship between CO₂ emissions and economic growth. In the third part, we look at population growth as an important factor impacting economic prosperity. In sum, these studies show a robust association between economic growth and environmental and demographic variables, but the nature and strength of this association vary among countries, over time, and with different research approaches.

The relationship between economic growth and changes in land use has been studied by several authors. Deng et al. (2010) investigated the connection between economic development and urban land expansion in China using land use data derived from satellite images, socioeconomic statistics, and spatial econometric techniques. The results indicated that economic growth strongly influenced urban expansion, with 10% growth in GDP associated with about 3% expansion of urban land. This result suggests that economic growth may require high land demands due to enhanced urbanization and development activities.

Similarly, He et al. (2014) employed structural equation modeling, correlation analysis, and geographical analysis to analyze the relationship between land-use changes and GDP growth in urban China. The results showed that economic growth led to the transformation of agricultural land to urban and industrial areas. Land development has been found to have a positive impact on economic growth through industrial development, which shows a potentially mutual relationship between land modification and economic development. Further studies on land use and land cover change relative to regional economic development in China were conducted by Chen et al. (2020). The results showed that the relationship between construction land and economic indicators such as GDP and industrial output was significant, and the link between land development and regional economic performance was further reinforced.

However, the economic effects of land development are not always favorable. With the use of a dataset of 30 Chinese provinces from 2004 to 2019, Lin et al. (2023) found that land expansion was initially beneficial to economic growth, but later overuse or inefficient land utilization decreased economic efficiency due to resource misallocation. These studies suggest that there may be a trade-off, where changes in land utilization can improve economic progress through urbanization, industrialization and infrastructure improvement, but inefficient land allocation can reduce economic efficiency. New evidence indicates that the economic impacts of land-use change are not only a function of the scale of land change, but also of the efficiency of land resource management.

The second category of literature explores the relationship between CO₂ emissions and economic growth. Empirical evidence is mixed, with some studies finding a positive association and others finding distinct or time-dependent effects. Rahman et al. (2020) examined the relationship between CO₂ emissions, trade liberalization, population density and economic growth in five South Asian countries for the period 1990–2017. The

study applied panel cointegration techniques in an augmented neoclassical growth framework and revealed that CO₂ emissions and population density had a beneficial effect on long-term economic growth. Thus, higher emissions might be associated with greater manufacturing, industrial activity and energy use during development.

Similar data are provided by Balsalobre-Lorente and Leitão (2020), who analyze CO₂ emissions, trade liberalization, renewable energy, tourism and economic performance in 28 countries of the European Union in the period 1995-2014. The empirical findings reveal that the relationship between CO₂ emissions and economic growth is significantly positive when estimated by fixed effects, Fully Modified Ordinary Least Squares (FMOLS) and Dynamic Ordinary Least Squares (DOLS). Zafar et al. (2025) recently studied the co-integrating relationships between CO₂ emissions and sustained economic growth for BRICS countries for the period of 2013-2024. The findings indicate that economies, especially those with a reliance on carbon-intensive sectors and energy, should expect an increase in emissions with rising economic activity.

Other studies have indicated adverse impacts on economic productivity from CO₂ emissions. Abbasi et al. (2021) employed the dynamic ARDL approach and frequency-domain causality analysis to investigate Pakistan from 1972 to 2018. The findings demonstrated that CO₂ emissions negatively influenced economic expansion, implying that the enduring economic consequences of ecological decline may surpass the benefits derived from manufacturing methods that generate high emissions. In a similar vein, Gafsi (2025) recognized a negative impact of CO₂ emissions on economic growth in Saudi Arabia.

The dynamics in the immediate future and the far future may also vary. Androniceanu and Georgescu (2023) examined data from 25 European Union countries from 2000 to 2020, revealing that CO₂ emissions promote short-term GDP growth but impede long-term economic progress. This finding indicates that carbon-intensive economic activities may provide short-term financial benefits, but result in long-lasting environmental and economic consequences. The varied empirical results indicate that the effect of CO₂ emissions on economic growth depends on the economic structures, stages of development, energy dependencies, environmental policies, and evaluation periods of different countries.

A crucial factor affecting economic performance is population growth, necessitating an analysis of the relationship between environmental factors and economic development. Nonetheless, similar to the information regarding CO₂ emissions, earlier studies yield ambiguous findings. Furuoka (2009) established that, for Thailand between 1961 and 2003, with the ARDL bounds testing approach and Granger causality examination, population growth has a beneficial effect on long-term economic development. Rahman et al. (2017) also identified a positive correlation between population growth and economic advancement in a group of both developed and developing countries.

Saidi and Zaidi (2019) utilized the Generalized Method of Moments (GMM) approach and found that population growth has a beneficial impact on economic progress while simultaneously increasing CO₂ emissions. The results show that population growth has a

dual role: a growing population can increase labor availability, consumption and economic participation, but it can also increase the demand for energy and natural resources, thereby exacerbating environmental pressure. Similarly, Kuhe (2019) found that population growth had a positive impact on economic output in Nigeria in the long run, while the short-run effects were ephemeral.

Abdullah et al. (2015) found a negative association between population growth and economic growth in Bangladesh. The study found that rapid population growth may impede economic performance if the growth in supplies of productive resources, infrastructure and job opportunities does not keep up with the rate of growth of population. These contradictory findings suggest that the effects of population growth on the economy are contingent on the capacity of an economy to convert a growing population into effective human capital and to cope with the increased demand for land, infrastructure, energy and other resources.

In sum, the literature exhibits a strong empirical focus on the relationships between environmental factors and economic growth. However, there are some gaps. Much of the existing literature has dealt with CO₂ emissions and land use change in isolation without considering their effects in a wider economic growth framework. Secondly, the main body of research on land use change and its economic consequences is focused on China and other major economies, resulting in a significant shortage of empirical evidence for Malaysia. Third, although the relationship between population growth and economic performance has been extensively studied, incorporating land use change and CO₂ emissions may offer a more comprehensive understanding of the environmental and demographic pressures of economic development.

Therefore, this study adds to the existing literature by examining the effects of land-use change, carbon dioxide emissions, and population growth on the economic development of Malaysia using annual data from 1990 to 2023. The ARDL approach is used to distinguish between short-term dynamics and long-term relationships among the variables. The holistic framework provides detailed country-specific information on the relationship between land-use changes and environmental stress, as well as the long-term economic consequences for Malaysia. The empirical results have implications for sustainable land management, ecological governance and economic development.

Methodology

Data

This study is an empirical study on the impacts of land-use change and CO₂ emissions on economic growth in Malaysia with annual time series data for the period 1990-2023. The data are from the World Development Indicators (WDI) database and CEIC Data. The dependent variable is economic growth (real GDP per capita), and the explanatory variables are land use, CO₂ emissions and population growth. Table 1 summarises the variables, symbols, units of measurement, and sources of data.

Table 1

Variables and sources

Variables	Symbol of the Variable	Unit of Measurement	Data Sources
Economic Growth	RGDPPC	Real GDP per capita	CEIC Data
Land Use	AL	Arable land (% of land area)	WDI
Carbon Dioxide Emissions	CO ₂	Tonnes CO ₂ per capita, excluding LULUCF	WDI
Population Growth	POPG	Annual percentage change	CEIC Data

Empirical model

Based on the empirical approaches of Androniceanu and Georgescu (2023) and Zafar et al. (2025), this study proposes an empirical model to explore the relationship between land use, CO₂ emissions, population growth, and economic growth in Malaysia. The functional form of the model is given as follows:

$$RGDPPC_t = f(AL_t, CO_{2t}, POPG_t)$$

where $RGDPPC_t$ is real gross domestic product per capita at time t , AL_t is arable land as a percentage of total land area, CO_{2t} is carbon dioxide emissions per capita, and $POPG_t$ is annual population growth.

Where appropriate, variables are transformed into natural logarithms to reduce scale differences and allow estimated coefficients to be interpreted as elasticities. The empirical model is:

$$LRGDPPC_t = \beta_0 + \beta_1 LAL_t + \beta_2 LCO_{2t} + \beta_3 LPOPG_t + \varepsilon_t$$

where $\ln RGDPPC_t$ is the natural log of real GDP per capita, $\ln AL_t$ is the natural log of arable land, $\ln CO_{2t}$ is the natural log of CO₂ emissions per capita, $\ln POPG_t$ is the population growth, β_0 is the constant term, β_1 , β_2 and β_3 are the estimated coefficients, and ε_t is the error term.

Estimation Techniques

This study employs the Autoregressive Distributed Lag (ARDL) bounds testing approach proposed by Pesaran and Shin (1999) and Pesaran et al. (2001) to examine the short-run and long-run relationship between economic growth, land use, CO₂ emissions and population growth in Malaysia. The ARDL method is appropriate when the variables under consideration are integrated of order zero, $I(0)$, order one, $I(1)$, or a mixture of both, provided that no variable is integrated of order two, $I(2)$.

The variables' stationarity properties are tested using the Augmented Dickey-Fuller (ADF), Dickey-Fuller Generalised Least Squares (DF-GLS) and Kwiatkowski-Phillips-Schmidt-Shin (KPSS) unit root tests before the ARDL estimation. The null hypothesis of the ADF and DF-GLS tests implies the presence of a unit root, and the alternative hypothesis implies stationarity. In contrast, the KPSS test assumes stationarity under the null hypothesis. The application of these complementary tests allows us to be more confident in the order of integration of the variables and to guarantee that none of them is integrated of order $I(2)$.

The ARDL bounds test is used to examine the existence of a long-run relationship among the variables after performing the unit root analysis. The ARDL model can be expressed in unrestricted error correction form as;

$$\Delta \ln \text{RGDPPC}_t = \alpha_0 + \sum \phi_i \Delta \ln \text{RGDPPC}_{t-i} + \sum \theta_j \Delta \ln \text{AL}_{t-j} + \sum \delta_k \Delta \ln \text{CO2}_{t-k} + \sum \gamma_l \Delta \text{POPG}_{t-l} + \lambda_1 \ln \text{RGDPPC}_{t-1} + \lambda_2 \ln \text{AL}_{t-1} + \lambda_3 \ln \text{CO2}_{t-1} + \lambda_4 \text{POPG}_{t-1} + \varepsilon_t$$

where Δ is the first-difference operator, the summation terms represent the short-run dynamics, and the lagged level variables represent the long-run relationship.

The null hypothesis of the bounds test states that there is no long-run relationship between the variables:

$$H_0: \lambda_1 = \lambda_2 = \lambda_3 = \lambda_4 = 0$$

versus the alternative hypothesis:

$$H_1: \lambda_1 \neq \lambda_2 \neq \lambda_3 \neq \lambda_4 \neq 0$$

The calculated F-statistic is compared with the critical values of the lower-bound $I(0)$ and the upper-bound $I(1)$. If the F-statistic is greater than the upper-bound critical value, the null hypothesis of no cointegration is rejected. If the F-statistic is less than the lower-bound critical value, we do not reject the null hypothesis. An inconclusive result is returned if the value is between the lower and upper bounds.

Once cointegration is verified, an Error Correction Model (ECM) is estimated to explain the short-run behavior and the adjustment mechanism to restore the long-run equilibrium. Then the ECM can be written as:

$$\Delta \ln \text{RGDPPC}_t = \alpha_0 + \sum \phi_i \Delta \ln \text{RGDPPC}_{t-i} + \sum \theta_j \Delta \ln \text{AL}_{t-j} + \sum \delta_k \Delta \ln \text{CO2}_{t-k} + \sum \gamma_l \Delta \text{POPG}_{t-l} + \psi \text{ECT}_{t-1} + \varepsilon_t$$

where ECT_{t-1} is the error correction term at lag $t-1$, and ψ is the speed of adjustment to long-run equilibrium. Then, the ECT coefficient is expected to be negative and statistically significant for convergence to equilibrium.

Several diagnostic tests are used to check the adequacy and reliability of the estimated model. The Jarque-Bera test is employed to test the normality of the residuals, while the Breusch-Godfrey Lagrange Multiplier test is used to test serial correlation. The Breusch-Pagan-Godfrey test checks heteroscedasticity, and the Ramsey RESET test tests for possible model misspecification.

Finally, the stability of the estimation is tested by the Cumulative Sum of Recursive Residuals (CUSUM) and Cumulative Sum of Squares of Recursive Residuals (CUSUMSQ) tests. The estimated parameters are assumed to be stable if the CUSUM and CUSUMSQ statistics are within the 5% critical bounds over the sample period.

Results & Discussions

Unit Root Tests

Table 2 displays the findings of the ADF, DF-GLS, and KPSS Unit Root Tests. The findings of the Augmented Dickey-Fuller, Dickey-Fuller Generalized Least Squares, and Kwiatkowski-Phillips-Schmidt-Shin unit root examinations are displayed in Table 2. The variables are examined at level, $I(0)$, and first difference, $I(1)$, under two configurations: intercept alone and intercept with trend.

The outcomes of the ADF test indicate a combination of stationarity at the level. The LAL and LPOPG levels are predominantly non-stationary, but LRGDPPC and LCO2 exhibit stationarity contingent upon the specification. The LRGDPPC exhibits stationarity at the 10% significance threshold when analyzed with the intercept-and-trend model, while LCO2 demonstrates stationarity at the 10% level with the intercept-only model. In both models, all variables exhibit stationarity at the 1% significance level following initial differencing.

The DF-GLS findings are analogous, indicating that most variables lack stationarity in their levels. In the intercept-and-trend model, the LAL marginally rejects the null hypothesis of stationarity at the 10% significance threshold. LRGDPPC, LAL, and LPOPG exhibit stationarity following first differencing for both models. Stationarity for LCO2 is attained through the intercept and trend specification following initial differencing.

The KPSS outcomes yield ambiguous findings at the level. In the KPSS examination, the dismissal of the null hypothesis indicates non-stationarity. The findings from the LRGDPPC and LAL tests dismiss the null hypothesis of stationarity for the intercept-only model, while upholding the null hypothesis of stationarity for the intercept-and-trend model. LPOPG and LCO2 typically exhibit more substantial indications of non-stationarity in their values. The majority of the series exhibit stationarity following the initial differencing. Nevertheless, the first-differenced LCO2 series remains non-stationary when only an intercept is considered, yet it becomes stationary with the addition of a deterministic trend.

The trio of unit root tests collectively indicates that the variables exhibit a combination of $I(0)$ and $I(1)$ characteristics according to the employed criteria. Primarily, we observe no indication of any variable being integrated of the second order, $I(2)$. Consequently, the stationarity findings fulfil the primary requirement for employing the ARDL limits testing methodology.

Table 2

Unit root test results

Variable	ADF			
	Level		First Difference	
	Intercept	Intercept and Trend	Intercept	Intercept and Trend
LRGDPPC	-1.8084(0)	-3.3846(0)*	-4.6669(1)***	-4.8526(1)***
LAL	-1.3679(0)	-2.8554(0)	-6.0797(0)***	-5.9805(0)***
LCO2	-2.7706(0)*	-1.7634(0)	-6.3756(0)***	-6.8729(0)***
LPOPG	1.1205(4)	-1.1063(4)	-4.0826(3)***	-4.3389(3)***
Variable	DF-GLS			
	Level		First Difference	
	Intercept	Intercept and Trend	Intercept	Intercept and Trend
LRGDPPC	0.5664(0)	-2.5866(0)	-4.9973(0)***	-5.5295(0)***
LAL	-1.1277(0)	-2.9645(0)*	-6.1792(0)***	-6.0682(0)***
LCO2	-0.4477(0)	-1.4079(0)	-1.3078(2)	-6.2926(0)***
LPOPG	0.5837(5)	-1.4826(4)	-3.9134(3)***	-3.9596(3)***
Variable	KPSS			
	Level		First Difference	
	Intercept	Intercept and Trend	Intercept	Intercept and Trend
LRGDPPC	0.6872(5)**	0.0895(3)	0.1989(0)	0.0865(3)
LAL	0.6533(4)**	0.0774(3)	0.0528(1)	0.0394(1)
LCO2	0.6126(5)**	0.2027(4)**	0.5472(3)**	0.0899(5)
LPOPG	0.7664(4)***	0.1473(3)**	0.1059(3)	0.0617(4)

***, **, and *show significance level at 1%, 5%, and 10%, respectively

ARDL bounds test for cointegration

Subsequent to the unit root assessments, the ARDL bounds testing methodology is employed to examine the presence of a long-term correlation among the variables. The outcomes of the ARDL bounds test are presented in Table 3.

The computed F statistic is 5.8486. This exceeds the lower-bound $I(0)$ critical value of 3.272 and the upper-bound $I(1)$ critical value of 4.306 at the 5% significance threshold. This indicates the dismissal of the null hypothesis asserting the absence of a long-term association. The findings indicate cointegration among real GDP per capita, land utilization, CO2 emissions, and population expansion in Malaysia.

The existence of cointegration suggests that these variables could diverge in the short term; however, they are interconnected by a long-term equilibrium association. Consequently, the examination is performed by calculating the long-term coefficients and short-term dynamics through the ARDL error-correction model.

Table 3

ARDL bound test results

F-statistic	5.8486	K(3)
Critical value bounds		
Significance	Lower Bound I(0)	Upper Bound I(1)
10%	2.676	3.586
5%	3.272	4.306
1%	4.614	5.966

Long-run coefficients

The long-term coefficients of the ARDL model are displayed in Table 4. The correlation between real GDP per capita and population increase is inversely related and statistically meaningful. The projected coefficient for LPOPG is -1.2954, with a p-value of 0.0002, indicating that the LPOPG coefficient is statistically significant at the 1% threshold. In this research, we employed a log-log model and discovered that, all else being equal, a 1% increase in population growth results in an approximate 1.30% decline in real GDP per capita over the long term.

The adverse long-term correlation may suggest that if the expansion of productive capacity, employment, infrastructure, and capital accumulation fails to match population growth, then population growth intensifies the strain on economic resources. This is in accordance with the findings of Abdullah et al. (2015), who found population increase and economic advancement in Bangladesh to be inversely correlated. However, it is contrary to the findings of Furuoka (2009), Rahman et al. (2017), Saidi and Zaidi (2019) and Kuhe (2019), who find a positive impact of population growth on economic outcomes. These conflicting results suggest that the economic impacts of population expansion are significantly dependent on a nation's capacity to convert population growth into productive labor and human capital.

Land usage exhibits a favorable correlation in the long term; nonetheless, it lacks statistical significance. The LAL coefficient is 1.7194, accompanied by a p-value of 0.1177. The projected coefficient suggests that a 1 percent rise in arable land correlates with a 1.72 percent rise in real GDP per capita; however, this association is not statistically significant at standard levels. Consequently, the findings lack adequate empirical support to indicate that alterations in arable land significantly impact Malaysia's long-term economic growth during the research duration.

The coefficient for LCO2 is positive although lacks statistical significance (0.1300, $p=0.3974$). A 1% rise in CO2 emissions correlates with about a 0.13% increase in real GDP per capita. The projected correlation lacks statistical significance. The positive coefficient might be associated with the strong connection between fossil fuel energy consumption, industrial output, transportation, and economic activity. However, the lack of statistical significance indicates that CO2 emissions do not serve as an independent factor influencing the long-term fluctuations in Malaysia's real GDP per capita when considering land use and population increase.

To summarize, the findings of the paper suggest that population growth is the only explanatory variable which has a statistically significant relationship with economic growth in the period under investigation. For land use and CO₂ emissions, the coefficients are positive, but not significantly different from zero in the long term.

Table 4

Long-run coefficients

Variables	Coefficient	Std. Error	t-Statistic	P-value
LAL	1.7194	1.0640	1.6160	0.1177
LCO ₂	0.1300	0.1512	0.8599	0.3974
LPOPG	-1.2954	0.2986	-4.3388	0.0002
C	9.4874	0.7301	12.9948	0.0000

Short-run coefficients

The short-run estimates of the error correction representation of the ARDL model are reported in Table 5. The coefficient of CointEq(-1) is -0.3668, which is negative and significant at the 0.0000 level of significance. The negative and high coefficient confirms that short-term deviations tend to follow the long-term equilibrium. The rectification of last year's imbalance stands at approximately 36.68% for the present year, signifying a slow pace of convergence to the long-term equilibrium.

The coefficient for the simultaneous alteration in land use, D(LAL), is positive (0.1660) although lacks statistical significance. The first lag of land use, D(LAL(-1)), exhibits a negative coefficient (-0.5279) that is statistically significant at the 1% level, but the second lag, D(LAL(-2)), presents a negative coefficient that is statistically significant at the 10% level. The findings indicate that alterations in land use do not exert an immediate statistically significant impact on economic growth, yet may yield adverse repercussions over time. The results suggest that the economic impacts of alterations in arable land may manifest over an extended timeframe, rather than concurrently.

We notice a comparable trend in CO₂ emissions. The coefficient of D(LCO₂) is positive, although it lacks statistical significance at the present moment. Conversely, D(LCO₂(-1)) and D(LCO₂(-2)) exhibit negative values that are statistically significant at the 1 percent threshold, with coefficients of -0.3301 and -0.3832, respectively. This finding indicates that although short-term variations in CO₂ emissions do not exhibit a significant correlation with real GDP per capita, the rise in emissions could adversely impact economic performance after a delay. One possible explanation is that early stages of manufacturing and industrialization may be associated with emission-intensive economic activities, but the environmental, health, energy efficiency, and resource costs of these activities may only be visible in later stages. But this conclusion should be taken with caution, as reported coefficients represent statistical correlation, rather than precise mechanisms through which emissions impact economic performance.

The relation between population growth and economic growth is transitory, and it varies with different time lags. The coefficient of D(LPOPG) is statistically significant and positive at the 10% level with a value of 0.2430 and a P-value of 0.0628. The coefficient of D(LPOPG(-1)) is not statistically significant, but the coefficient of D(LPOPG(-2)) is positive

and statistically significant at the 1% level with a value of 0.7583. The findings suggest that population growth could have a positive impact on economic performance in the short run, especially with a two-period lag. In the very short term, a growing population can increase the supply of labor, increase consumption and aggregate demand, thus easing economic activity.

Interestingly, the positive short-term correlation between population growth and economic growth is in sharp contrast with the negative long-term coefficient, as shown in Table 4. This differential suggests that population increase could bring immediate economic benefits from a larger workforce and domestic consumption but could, in the longer term, impose greater stress on capital, infrastructure, employment opportunities and other productive assets. The results therefore underline the importance of the distinction between short-term dynamics and long-term consequences in the assessment of the economic implications of population growth.

Table 5

Short-run coefficients from ECM with ARDL model

Variables	Coefficient	Std. Error	t-Statistic	P-value
D(LAL)	0.1660	0.1423	1.1666	0.2564
D(LAL(-1))	-0.5279	0.1823	-2.8964	0.0086
D(LAL(-2))	-0.2961	0.1632	-1.8149	0.0839
D(LCO2)	0.0654	0.1301	0.5025	0.6206
D(LCO2 (-1))	-0.3301	0.1164	-2.8373	0.0099
D(LCO2 (-2))	-0.3832	0.1027	-3.7330	0.0012
D(LPOPG)	0.2430	0.1237	1.9651	0.0628
D(LPOPG(-1))	0.0979	0.1608	0.6090	0.5490
D(LPOPG(-2))	0.7583	0.1987	3.8168	0.0010
CointEq(-1)	-0.3668	0.0610	-6.0108	0.0000

Diagnostic and stability tests

The sufficiency and dependability of the estimated ARDL model are assessed by several diagnostic evaluations. The findings of the normality, serial correlation, heteroscedasticity, and model specification assessments are encapsulated in Table 6.

The p-value for the Jarque-Bera test is 0.0529. Consequently, we do not reject the null hypothesis of normality of residuals at the 5% significance level, suggesting that the residuals are roughly normally distributed. The Breusch-Godfrey LM test has a p-value of 0.3081, indicating an absence of serial correlation. In a similar vein, the Breusch-Pagan-Godfrey test yields a p-value of 0.1913, indicating that the null hypothesis of homoscedasticity remains unrefuted. Consequently, the proposed model lacks indications of heteroscedasticity.

The p-value for the Ramsey RESET test is 0.1157. This number exceeds the 5% significance threshold; hence, we are unable to reject the null hypothesis asserting that the functional form is accurate. Consequently, the findings offer no indication that the model is incorrectly defined. In general, the diagnostic assessments suggest that the estimated ARDL model satisfies the fundamental residual and specification criteria.

Table 6

Diagnostic test results

Diagnostic tests	Coefficient	p-value	Decision
Jarque-Bera test	5.8795	0.0529	Residuals are normally distributed.
Breusch-Godfrey LM test	1.0389	0.3081	No serial correlation exists.
Breusch-Pagan-Godfrey test	17.1773	0.1913	No heteroscedasticity exists
Ramsey RESET test	2.7661	0.1157	Model specified correctly

Moreover, the stability of parameters is tested by CUSUM and CUSUMSQ tests. As can be seen in Figure 1, both graphs are within the 5% critical limits during the estimation interval. This implies that the projected coefficients are stable over the sample period and there is no evidence of parameter volatility.

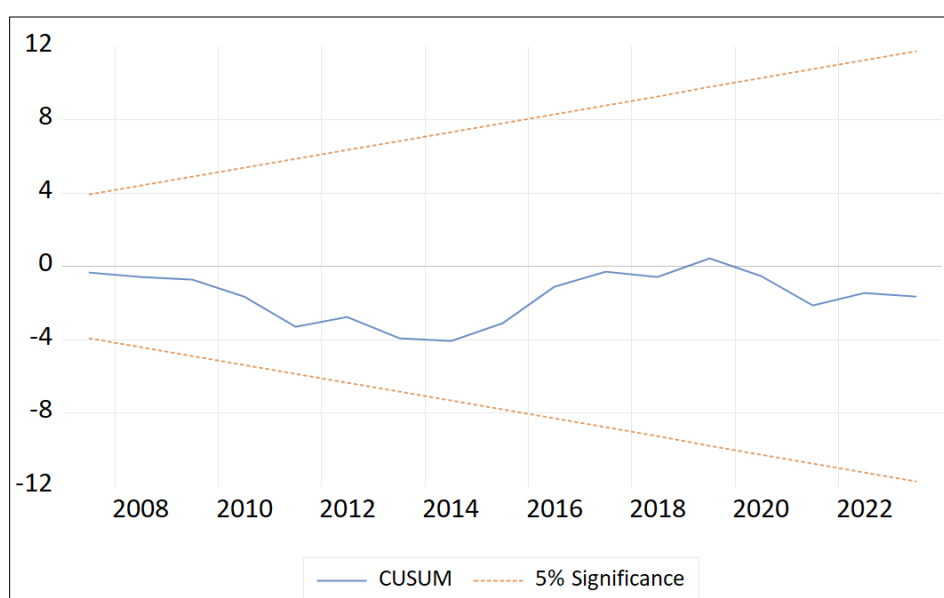
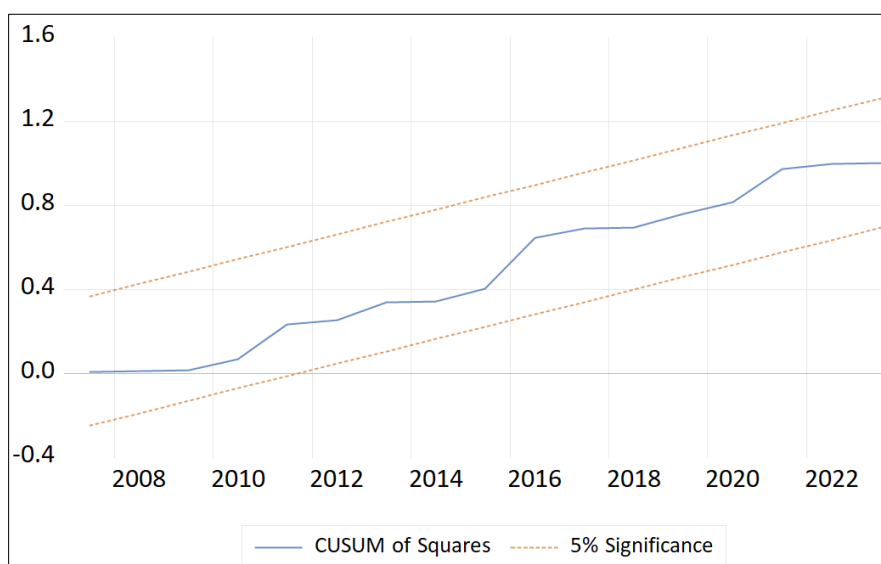


Figure 1. CUSUM and CUSUMSQ Stability Tests



Conclusion

The present study employed the Autoregressive Distributed Lag (ARDL) technique to analyze the effect of land use, carbon dioxide emissions and population growth on Malaysia's economic growth for the period 1990-2023. The unit root tests using ADF, DF-GLS and KPSS methodologies confirmed that none of the variables is integrated of order two, $I(2)$; thus, the variables conform to the ARDL estimation requirements. In addition, the long-run association among the variables was confirmed by the ARDL bounds test.

Empirical evidence indicates that population growth has a negative and significant effect on economic growth in the long run. In contrast, population growth has an immediate advantage at some lag intervals. In the short run, population growth may boost economic performance through a larger labor force and larger domestic consumption, but in the longer term, continued population growth may put increasing strain on productive resources, employment, infrastructure and capital formation.

The enduring relationship between land utilization and economic expansion is affirmative although statistically inconsequential. In the immediate term, the current impact of land use is statistically negligible; however, the delayed effects are adverse, with the first lag being statistically significant at the 1% threshold and the second lag significant at the 10% threshold. This indicates that alterations in land utilization might not immediately impact economic performance, but could produce subsequent economic consequences.

Additionally, a favorable albeit negligible long-term correlation exists between CO₂ emissions and economic expansion. The immediate impact is likewise statistically negligible in the near term. The lagged effects of the first and second periods are negative and statistically significant. The findings indicate that economic activity can initially correlate with higher CO₂ emissions, although this may be linked to negative economic repercussions in later periods. The substantial negative error correction coefficient further corroborates that these short-term discrepancies are rectified toward the long-term equilibrium at around 36.68% of the imbalance per year. Furthermore, the diagnostic and stability assessments indicate that the proposed model is appropriately formulated, devoid of significant econometric issues and remains stable during the analysis period.

The findings bear significance for sustainable development in Malaysia. The adverse long-term impact of population growth suggests that demographic increase must be accompanied by enhancements in labor productivity, job prospects, human capital advancement, infrastructure, and technical capabilities. Consequently, measures that promote education, skill enhancement, and worker efficiency are crucial for guaranteeing that population expansion favorably influences long-term economic performance.

The results further underscore the importance of sustainable land and environmental stewardship. Although land use and CO₂ emissions are not statistically significant over the long term, their adverse lagged short-term impacts suggest that environmental and resource constraints may have exerted some deferred influence on economic expansion. So, policy-makers should strengthen land-use planning, environmental impact assessments, renewable energy programs, energy-efficiency initiatives, and low-carbon development plans. Economic

growth should be driven more by productivity, innovation, technological progress, and efficient resource use, and less by resource-intensive efforts.

The results imply that Malaysia needs to balance demographic progress, environmental protection and economic productivity growth to achieve sustainable economic growth. Future research may extend the analysis by including other environmental and macroeconomic factors, different measures of land-use change, or structural break approaches to better understand the relationship between environmental factors and economic growth.

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