

AGRICULTURE, RENEWABLE ENERGY, AND CO2 EMISSIONS IN MALAYSIA: AN ARDL ANALYSIS

SAZALI, M. A.¹ – HUAY, C. S.^{1*} – JAMALUDIN, S.¹ – ALPANDI, R. M.¹

¹ *Department of Economics and Finance, University of Technology MARA, Selangor, Malaysia.*

**Corresponding author
e-mail: siewhuaychong[at]uitm.edu.my*

(Received 18th March 2026; revised 26th June 2026; accepted 28th July 2026)

Abstract. The development of renewable energy has become an increasingly important factor in reducing environmental degradation, and in promoting sustainable economic development. The existing empirical literature has examined the nexus between economic growth, renewable energy, agriculture and environmental degradation in isolation or focus in sectors. However, the empirical literature that jointly analyze how agriculture activity, renewable energy and how these relationships behave in both short run and long run are absent in the context of Malaysia. It is important to understand the interconnection between agriculture activities with the renewable energy in Malaysia and uptake to shape the short run and long run emissions trajectories. This study aims to investigate the nexus between agriculture and renewable energy on carbon emissions in Malaysia. This study examines the impact of agriculture, renewable energy consumption and economic growth on CO2 emissions by using annual data for the years 1990–2020 by using the Autoregressive Distributed Lag (ARDL) model to investigate both the short-run and long-run relationships between the variables. The results show that renewable energy consumption and sustainable agricultural development are helpful to reduce CO2 emissions, while the economic growth increases environmental pressure through higher energy demand and industrial activities. The study emphasizes the need for integrating renewable energy policies and sustainable agricultural practices to support Malaysia's transition to a low-carbon economy. The findings have important implications for policy makers in developing strategies that balance economic development, environmental sustainability and agricultural productions.

Keywords: *agriculture, renewable energy, carbon emissions, economic growth, ARDL, Malaysia*

Introduction

In recent decades, the interconnection between climate change and environmental sustainability is pivotal for achieving climate goals, particularly in agriculture activities. Global warming and deterioration of the environment have been caused by the increasing use of energy, transport and agricultural activities through increase in carbon dioxide (CO2) emission. The growing concentration of greenhouse gases in the atmosphere has intensified climate-related problems, including extreme weather, loss of biodiversity, rising sea levels and threats to food security. As a result, governments and international organizations have adopted a variety of environmental policies and sustainability frameworks, such as the Paris Agreement and the United Nations Sustainable Development Goals (SDGs), to promote low-carbon economic development and sustainable resource management. As a rapidly growing economy, Malaysia is under increasing pressure to reconcile economic development with environmental sustainability. Agriculture continues to be a major economic sector in the country with a substantial contribution to employment, rural development and national income. But agricultural activities also have environmental challenges, especially carbon emissions from deforestation, fertilizer use, land clearing and burning of agricultural waste.

The development of renewable energy has become an increasingly important factor in reducing environmental degradation, and in promoting sustainable economic development. Malaysia has undertaken a number of initiatives on renewable energy such as the Renewable Energy Act 2011, Feed-in Tariff (FiT), Net Energy Metering (NEM) and Large-Scale Solar (LSS) programs to promote the uptake of renewable energy. Despite the advances in renewable energy technologies and policy initiatives, fossil fuel is still the primary energy source in the country. This dependence of fossil fuel sustains environmental problems high green house gas (GHG) and pollution. The existing empirical literature has examined the nexus between economic growth, renewable energy, agriculture and environmental degradation in isolation or focus in sectors. However, the empirical literature that jointly analyze how agriculture activity, renewable energy and how these relationships behave in both short run and long run are absent in the context of Malaysia. It is important to understand the interconnection between agriculture activities with the renewable energy in Malaysia and uptake to shape the short run and long run emissions trajectories (Latif et al, 2021). This study, therefore, aim to investigate the nexus between agriculture and renewable energy on carbon emissions in Malaysia. This study examines the impact of agriculture, renewable energy consumption and economic growth on CO2 emissions by using annual data for the years 1990–2020. The findings are expected to contribute to the body of knowledge in environmental economics and useful policy recommendations for sustainable development in Malaysia.

Literature reviews

Previous research has found out that economic development and industrialization are key determinants of carbon emissions in developing nations which have reliance on fossil fuel-based energy sources. The environmental Kuznets curve (EKC) hypothesis is widely used explanation for linkage between economic development and environmental degradation. The inverted U-shaped in Kuznets curve shows environmental degradation increases in early stages of economic development. However, the trend starts reversing once a nation reaches a certain income level due to adoption of clean technologies and implementation of environmental regulations (Claire and Widyawati, 2023; Htike et al., 2022; Konya, 2022; Nassani et al., 2021; Musibau et al., 2020). This foundation has been applied to CO2 emissions, agriculture activity and broader indicator across the regions, including ASEAN, Latin America and Africa (Sadekin et al., 2025; Konya, 2022; Leal and Marques, 2022; Udemba, 2021; Nassani et al., 2020)

It should be noted that agriculture activities such as deforestation, fertilizer application, land cultivation, and open burning for agricultural purposes are widely recognized as the major contributors to environmental pollution and green house emissions in developing countries (Raihan et al., 2022). In response to these environmental pollution, sustainable agriculture approaches including precision agriculture, agroforestry, organic farming, and effective land management practices can contribute to decreasing environmental degradation while promoting the long-term sustainability. It is widely acknowledged that renewable energy plays a significant role in mitigating carbon emission levels and promoting environmental sustainability. The use of clean energy forms like solar energy, biomass energy, hydro power, and wind energy offers a better alternative than fossil fuels, thereby reducing greenhouse gas emissions (Khan et al., 2021). Negative effects of consumption of renewable energy on

CO2 emissions has been observed previously. Hence, increased consumption of renewable energy promotes sustainability and environmental protection.

Several studies have empirically assessed linkage between renewable energy consumption, agricultural activities and carbon emissions in developing nations. For example, Malaysia has experienced the reduction in carbon emission through greater renewable energy consumption as highlighted by Raihan et al. (2022). The relationship between agricultural activities and environmental degradation largely depends on the level of sustainability embedded within the farming practices. Similarly, Liu et al. (2019) reported that the expansion of renewable energy contributes positively to the environmental sustainability in developing nations. However, the effects of agricultural activities on the environment are strongly shaped by sustainability of the farming process is, as well as the adoption of technological advances and effectiveness of environmental policies implemented within the agriculture sector. Regarding methodological aspect, most of the previous studies utilized advanced econometric methods including Fully Modified Ordinary Least Squares (FMOLS), Vector Error Correction Models (VECM), Dynamic Ordinary Least Squares (DOLS) and Autoregressive Distributed Lag (ARDL) (Raihan and Tuspekova, 2023; Isik et al., 2019). Among those techniques, the use of ARDL model is appropriate when examining the association between economic variables and environmental degradation. Moreover, the ARDL approach is considered appropriate as it enables the examination of both short-run and long-run relationships among variables with different orders of integration.

Notwithstanding the substantial literature on economic development and environmental degradation, there are few studies which have explored nexus between agriculture and renewable energy concerning carbon emissions in Malaysia. Therefore, this study makes contributions to the existing literature by studying relationship between agriculture, renewable energy consumption, economic growth, and carbon emissions simultaneously with updated Malaysian time-series data from 1990 to 2020.

Materials and Methods

This study uses a quantitative research approach to examine the relationship between agriculture, renewable energy consumption, economic growth and carbon emissions in Malaysia. Annual time series data for the period 1990-2020 were obtained from World Bank's World Development Indicators (WDI). The dependent variable of the study is carbon dioxide emissions (CO2) in metric tons per capita. The independent variables are agriculture value added (AVA), renewable energy consumption (RE) and gross domestic product (GDP). Agriculture value added is the contribution of agriculture, forestry and fisheries to the economy; renewable energy consumption is the share of total final energy consumption that is derived from renewable sources of energy. This study employs the Autoregressive Distributed Lag (ARDL) model of Pesaran et al., to explore short run and long run relationships among the variables. The ARDL model is appropriate because it can handle variables that are integrated at level $I(0)$ and first difference $I(1)$ making it suitable for small sample size and mixed order of integration. The Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root tests were conducted prior to estimating ARDL to determine the stationarity properties of the variables. The ARDL Bounds Testing approach was then employed to test for the existence of cointegration among the variables.

The functional model is specified as follows:

$$CO_{2t} = f(AVA_t, RE_t, GDP_t)$$

The econometric model is expressed as:

$$CO_{2t} = \beta_0 + \beta_1 AVA_t + \beta_2 RE_t + \beta_3 GDP_t + \varepsilon_t$$

Where: CO₂ = Carbon dioxide emission; AVA = Agricultural value added; RE = Renewable energy consumption GDP = Gross domestic product; ε = Error term. Before estimating the ARDL model, the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root tests were conducted to examine the stationarity properties of the variables. This step is necessary to ensure that none of the variables is integrated at the second difference, I(2), because the ARDL bounds testing approach is only appropriate when the variables are integrated at I(0), I(1), or a mixture of both. The Autoregressive Distributed Lag (ARDL) model was used to examine the short-run and long-run relationships among the variables. The ARDL approach is suitable for this study because it can be applied to a relatively small sample size and to variables with mixed orders of integration. The general ARDL model is expressed as follows:

$$\Delta CO_{2t} = \alpha_0 + \sum \beta_{1i} \Delta CO_{2t-i} + \sum \beta_{2i} \Delta AVA_{t-i} + \sum \beta_{3i} \Delta RE_{t-i} + \sum \beta_{4i} \Delta GDP_{t-i} + \lambda_1 CO_{2t-1} + \lambda_2 AVA_{t-1} + \lambda_3 RE_{t-1} + \lambda_4 GDP_{t-1} + \mu_t$$

Where Δ denotes the first-difference operator, β represents the short-run dynamic coefficients, λ represents the long-run coefficients, and μ_t is the white-noise error term. The ARDL bounds test was used to determine the existence of cointegration among the variables. If the computed F-statistic exceeds the upper bound critical value, the null hypothesis of no cointegration is rejected, indicating the presence of a long-run relationship. After confirming cointegration, the Error Correction Model (ECM) was estimated to examine the short-run adjustment process towards long-run equilibrium.

The ECM model is specified as follows:

$$\Delta CO_{2t} = \alpha_0 + \sum \beta_{1i} \Delta CO_{2t-i} + \sum \beta_{2i} \Delta AVA_{t-i} + \sum \beta_{3i} \Delta RE_{t-i} + \sum \beta_{4i} \Delta GDP_{t-i} + \lambda ECT_{t-1} + \varepsilon_t$$

Where, ECT_{t-1} represents the lagged error correction term. A negative and statistically significant ECT confirms the existence of long-run equilibrium and shows the speed at which short-run disequilibrium adjusts back to the long-run path.

Results and Discussion

The descriptive statistics showed that there was a significant variation in the carbon emissions, agriculture value added, renewable energy consumption, and the growth of GDP in Malaysia during the study period. Economic growth and industrialization resulted in growing carbon emissions, whereas government renewable energy initiatives resulted in a slow increase in renewable energy consumption. The results of the Augmented Dickey-Fuller (ADF) and the Phillips-Perron (PP) tests indicated that the

variables were integrated at different orders of I(0) and I(1), thus confirming the appropriateness of the ARDL approach (Table 1). Before estimating the ARDL model, the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root tests were conducted to examine the stationarity properties of the variables. The results indicate that the variables are integrated at mixed orders. CO₂ and GDP become stationary at first difference, while agriculture value added and renewable energy consumption require further differencing in the reported thesis output. For the purpose of the journal paper, the result should be reported carefully and consistently with the final accepted ARDL assumption that no variable used in the ARDL estimation is treated as I(2) (Table 2).

Table 1. Descriptive analysis.

Variable	Mean	Median	Max	Min	Std. Dev.	Skewness	Kurtosis	Jarque -Bera
CO ₂ Emissions	5.963	6.431	7.719	3.118	1.403	-0.513	1.957	2.763
Agriculture Value Added	173,075,184	118,592,313	341,254,567	66,990,157	89,711,325	0.376	1.527	3.535
Renewable Energy Consumption	4.426	4.200	8.300	2.000	1.750	0.561	2.228	2.396
GDP	6,631.129	5,536.837	11,132.103	2,513.241	3,043.872	0.257	1.442	3.477

Table 2. Unit root test results.

Variable	ADF Level	PP Level	ADF First Difference	PP First Difference	ADF Second Difference	PP Second Difference
CO ₂ Emission	0.2545	0.7800	0.0000	0.0000	0.0003	0.0001
Agriculture	0.7810	0.7800	0.2708	0.0004	0.0000	0.0000
Renewable Energy	0.7174	0.3515	0.1786	0.1884	0.0000	0.0000
GDP	0.7927	0.7938	0.0008	0.0010	0.0000	0.0001

The selected model for the analysis is ARDL(1,1,1,0). The ARDL estimation results show that the lagged value of CO₂ emissions is positive and statistically significant, indicating that past carbon emissions influence current carbon emissions. Agriculture value added has a negative and statistically significant coefficient, suggesting that an increase in agricultural value added is associated with a reduction in CO₂ emissions. This implies that improvements in agricultural productivity, when supported by sustainable practices, may help reduce environmental pressure. Renewable energy consumption shows a positive short-run coefficient but is not statistically significant at the 5% level. This finding indicates that the environmental benefit of renewable energy may not be immediate but may become more evident in the long run as renewable energy adoption expands and fossil fuel dependence declines. GDP has a positive and statistically significant relationship with CO₂ emissions. This indicates that Malaysia's economic growth remains associated with higher carbon emissions, most likely due to industrialisation, urbanisation, transportation, and higher energy demand. This finding suggests that economic expansion may continue to increase environmental pressure unless it is supported by cleaner technologies, renewable energy investment, and stronger environmental regulation (Table 3).

Table 3. ARDL estimation results.

Variable	Coefficient	Std. Error	t-Statistic	Probability
CO ₂ Emission (-1)	0.4232	0.0893	4.7396	0.0001
Agriculture VA	-7.6197E-11	2.1641E-11	-3.5210	0.0018
Agriculture VA (-1)	-5.4191E-11	1.2739E-11	-4.2538	0.0003
Renewable Energy	0.1187	0.0798	1.4879	0.1503

Renewable Energy (-1)	-0.2979	0.1004	-2.9663	0.0069
GDP	0.0005	0.000083	6.3423	0.0000
Constant	3.0354	0.5098	5.9535	0.0000

The ARDL bounds test confirms the existence of a long-run relationship among CO₂ emissions, agriculture value added, renewable energy consumption, and GDP. The computed F-statistic is 12.0516, which exceeds the upper bound critical values at conventional significance levels. Therefore, the null hypothesis of no cointegration is rejected. This confirms that the variables move together in the long run. The Error Correction Model further supports the existence of a stable long-run relationship. The coefficient of the error correction term, $CointEq(-1)$, is -0.5768 and statistically significant. This means that approximately 57.68% of short-run disequilibrium is corrected in each period. The negative and significant error correction term confirms that the model adjusts back towards long-run equilibrium after short-run shocks. The diagnostic tests confirm that the ARDL model is reliable and robust. The Breusch-Godfrey Serial Correlation LM Test shows that there is no serial correlation problem. The Breusch-Pagan-Godfrey Heteroskedasticity Test indicates that the model does not suffer from heteroskedasticity. The Jarque-Bera Normality Test confirms that the residuals are normally distributed. In addition, the CUSUM and CUSUM of Squares tests show that the estimated model is stable because the plotted lines remain within the 5% significance boundaries (*Figure 1* and *Figure 2*).

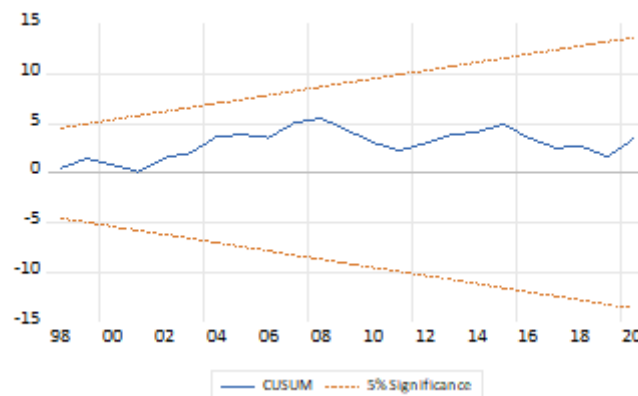


Figure 1. CUSUM test for stability.

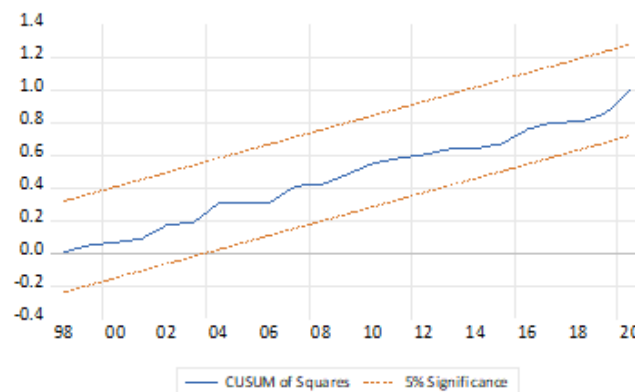


Figure 2. The stability test (CUSUM of Squares).

The findings of this analysis confirm the need for renewable energy and sustainable agriculture in reducing carbon emissions in Malaysia. Renewable energy exerts a negative relationship on CO2 emissions negative correlation between renewable energy consumption and carbon emissions is expected because, according to the literature review, renewables help achieve environmental sustainability. For example, the renewable energy programs initiated in Malaysia, including Large Scale Solar (LSS), Feed-in Tariff (FiT) and Net Energy Metering (NEM), have contributed significantly towards reduction of environmental pollution and promotion of sustainable agriculture in the country. The negative correlation between the agriculture value added and carbon emissions means that agricultural sustainability could help reduce the negative effect of economic development and maintain high agricultural output. Agricultural technologies, precision farming, agroforestry and environmental-friendly farming techniques may contribute to lower carbon emissions and sustainability of the industry. However, the positive relationship between GDP and carbon emissions is explained by the fact that economic development increases environmental burden owing to industrialization, urbanization and increased energy use. This correlation confirms the opinion expressed in the literature review according to which developing countries face the problem of environmental degradation associated with rapid economic development. The significant negative error correction term testifies to the existence of long-term equilibrium relationships between carbon emissions, agriculture value added, GDP and renewable energy consumption. This means that agricultural activities, renewable energy consumption and GDP eventually balance out carbon emissions. Overall, the results of the analysis confirm the necessity of taking into account factors related to agricultural sustainability and renewable energy development in environmental and economic policies of Malaysia.

Conclusion

This study assessed the interplay between agriculture, renewable energy consumption, economic growth, and carbon emissions using time series data from 1990 to 2020 in Malaysia. Through the ARDL approach, both short-run and long-run relationships were effectively captured in the study. The findings indicate that sustainable agricultural production and renewable energy consumption help mitigate the effects of carbon emissions in Malaysia. On the other hand, economic growth negatively impacts the environment since there will be more industrial and energy consumption activities. Given the long-run emissions benefits associated with renewable energy, policy instruments that accelerate the uptake of renewable energy are important. From a policy implication point of view, this study recommends that Malaysia needs to promote renewable energy generation and use and promote sustainable agriculture practices for reducing environmental degradation and sustainability purposes. There should be government policies to encourage renewable energy investment and improve sustainable agriculture. Future research could be expanded by incorporating additional explanatory variables such as technological innovation, urbanisation, environmental regulations, and climate-related factors to provide a more comprehensive understanding of environmental sustainability.

Acknowledgement

This research is self-funded.

Conflict of interest

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

REFERENCES

- [1] Claire, B.E., Widyawati, D. (2023): Impact of industrialization and renewable energy on carbon dioxide emission in 9 ASEAN countries. – *Economic Journal of Emerging Markets* 15(2): 183-198.
- [2] Htike, M.M., Shrestha, A., Kakinaka, M. (2022): Investigating whether the environmental Kuznets curve hypothesis holds for sectoral CO2 emissions: Evidence from developed and developing countries. – *Environment, Development and Sustainability* 24(11): 12712-12739.
- [3] Işık, C., Ongan, S., Özdemir, D. (2019): Testing the EKC hypothesis for ten US states: An application of heterogeneous panel estimation method. – *Environmental Science and Pollution Research* 26(11): 10846-10853.
- [4] Khan, M., Abbas, F., Rehman, A. (2021): **The supplied citation “Renewable energy consumption and environmental sustainability: Evidence from developing countries. – *Renewable Energy* 172: 367-375
- [5] Konya, S. (2022): Panel estimation of the environmental Kuznets curve for CO2 emissions and ecological footprint: Environmental sustainability in developing countries. – *Folia Oeconomica Stetinensia* 22(2): 123-145.
- [6] Latif, S.N.A., Chiong, M.S., Rajoo, S., Takada, A., Chun, Y.-Y., Tahara, K., Ikegami, Y. (2021): The trend and status of energy resources and greenhouse gas emissions in the Malaysia power generation mix. – *Energies* 14(8): 26p.
- [7] Leal, P.H., Marques, A.C. (2022): The evolution of the environmental Kuznets curve hypothesis assessment: A literature review under a critical analysis perspective. – *Heliyon* 8(11): 17p.
- [8] Musibau, H.O., Nepal, R., Vespignani, J., Yanotti, M. (2020): The moderating role of green energy and energy-innovation in environmental Kuznets: Insights from quantile-quantile analysis. – *Globalization Institute Working Paper No. 385, Federal Reserve Bank of Dallas* 19p.
- [9] Nassani, A.A., Abro, M.M.Q., Batool, R., Shah, S.H.A., Hyder, S., Zaman, K. (2021): Go-for-green policies: The role of finance and trade for sustainable development. – *International Journal of Finance & Economics* 26(1): 1409-1423.
- [10] Raihan, A., Tuspekova, A. (2023): Toward a sustainable environment: Nexus between economic growth, renewable energy use, agricultural productivity, and carbon emissions in ASEAN countries. – *Environmental Science and Pollution Research* 30(12): 33789-33805
- [11] Raihan, A., Begum, R.A., Said, M.N.M. (2022): Dynamic impacts of renewable energy, agriculture, and economic growth on carbon emissions in Malaysia. – *Environmental Science and Pollution Research* 29(40): 60521-60538
- [12] Sadekin, M.N., Akter, A., Ahmed, M.T., Zubayer, S.A. (2025): The impact of renewable energy consumption on CO2 emissions: Evidence from selected Asia and the Pacific countries. – *Research Square Preprint* 16p.
- [13] Udemba, E.N. (2021): Implication of coal expansion and regional energy trading center to climate goal: Dual sustainability analysis. – *Research Square Preprint* 22p.