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The impact of financial development on environmental quality: evidence from Malaysia

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Abstract
This paper examined the impacts of financial development on environmental quality in Malaysia, using the sum of financial access, depth, and efficiency as auxiliary variables for financial development from 1987 to 2020. The autoregressive distributed lag method was used to examine whether a level relationship (long run) existed among the variables. The paper found a long-run relationship among the variables. Financial development, population growth, economic growth, and energy usage positively significantly contribute to environmental degradation in both the short and long run, while squared economic growth significantly enhanced environmental quality in both the short and long run. Hence, environmental carbon Kuznets curve (ECKC) hold in Malaysia.

Keywords Financial development · Carbon emission · Economic growth · Environmental quality

Jel classification F3 · C3 · Q4 · O1 · Q5

Introduction

Environmental degradation is assumed a dangerous proportion, heightened concern by proponents of sustainable development in recent times. This socio-economic menace has drawn the attention of researchers and policymakers in both developed and developing economies. Increased attention is devoted to the problem of carbon dioxide emission in a developed country in recent times. The search for factors responsible for continuous increase in carbon dioxide emission is endless, and studies aimed at providing answers have produced mixed results. Human activities such as production, consumption, population, transportation, and urbanization, are regarded as the main determinants of carbon dioxide emissions. Financial development is associated with environmental quality. According to Zhang (2011), financial development influences environmental quality via three channels: Firstly, stock market development assists listed companies to lower financing costs, increase financing channels, diversifies risk, and optimizes asset/liability structure; this enables them to buy new installations and invest in new projects and consequently increase energy consumption and carbon emissions. Secondly, financial development might attract foreign direct investment, which enhances economic growth and exacerbates carbon emissions, hence increasing their carbon dioxide emission footprint (Zhang 2011). Also, a well-developed financial sector could aid in adopted energy-saving methods of production and environmentally friendly consumer products. Thus, the financial sector plays a major role in developing and developing countries' economic development. Efficient management of the financial system allows countries to use financial resources productively, even with limited financial resources. This creates a socio-economic environment that is more favorable for the progress of innovation and stimulates economic development (Furuoka 2015). A well-developed and managed financial system attracts investors, boosts the

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stock market, and improves economic activities' efficiency. Financial development is an essential part of every economy, promoting the economy's stock market and banking activities. The financial sector attracts foreign direct investment, which aids in the financial system of a country by improving economic efficiency. There is a strong correlation between the financial system and economic activities (Sadorsky 2011).

There are two schools of thought concerning the effects of financial development on environmental quality. One view holds that efficient financial intermediation increases investment opportunity, increasing lending to firms and households. This will encourage firms and consumers to invest in new financial projects and purchase high earned consumable items, thereby raising energy consumption (such as refrigerators, air conditioners, television, automobiles, and machinery). The growing energy consumption, in turn, increased carbon dioxide emissions into the atmosphere and organic pollutants into the earth's ecosystem (Abbasi and Riaz 2016; Bekhet et al. 2017; Shahbaz et al. 2010).

On the contrary, developed financial institutions and capital markets provide an opportunity for investable funds to renewable energy sector and loan as well as equity financing in funding green renewable energy projects, respectively. A well-developed financial system provides an avenue to offer credits for environmentally friendly projects at low financing costs. Besides, FDI may lead to local firms' technological innovation, reducing energy usage (Jalil and Feridun 2011). Therefore, financial development might be an incentive for increased energy substitution (which reduces energy consumption and CO_2 emission). The main idea is graphically explained in Fig. 1 below. Results or outcomes of research on financial development-environment quality nexus are ambiguous at best.

This research examines the relationship between carbon emissions and financial development in Malaysia, being a rapid financial developing economy. Following Acheampong's (2019) suggestion, this study utilized five indicators throughout the 1987–2020 periods. This paper is premised on Acheampong (2019), augmented with financial developments to establish the long-run co-integration relationships among CO_2 emissions, energy used, population, economic growth, financial development, and employed autoregressive distributive lag method. This research's specific contribution to literature is twofold; firstly, this research employed broader measured financial development indices (depth, access, and efficiency). Secondly, it provides policymakers with a clear and econometrics base that could help in policy formation to improve Malaysia's environmental quality and across the globe.

The rest of the paper is organized as follows: The "Brief literature review" section provides a brief literature review. The "Methodology and data" section gives detailed descriptions of methodology and data, while the "Empirical results and discussion" section discussed the empirical results

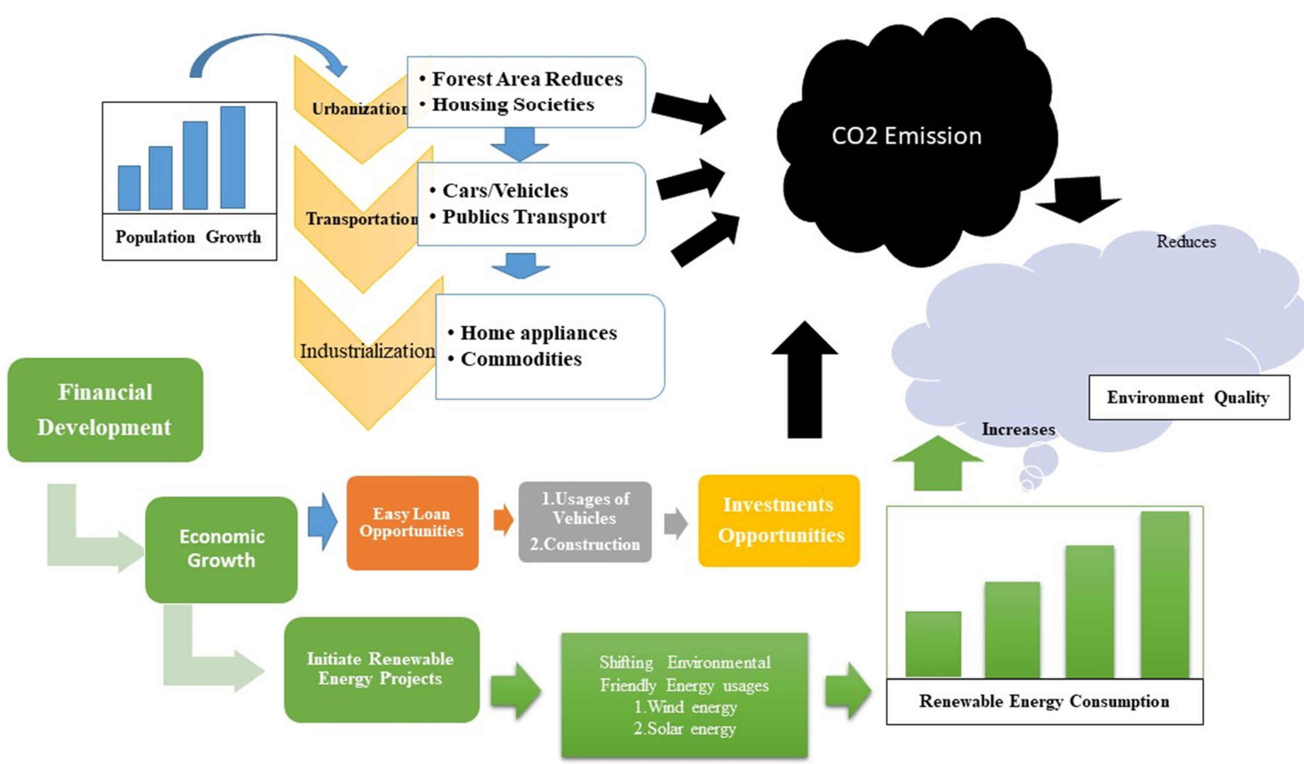

Fig. 1 Graphical presentation of the idea linking financial development to environmental pollution

obtained from our analysis, and the "Conclusion and policy implications" section concludes this research with policy implementations.

Brief literature review

Numerous studies have examined the relationship between financial development and carbon emission with diverse outcomes; this includes but is not limited to Ali et al.'s (2019) study of the dynamic links between carbon emissions and financial development in Nigeria, using ARDL bound test approach for the period of 1971–2010. They found financial development has a positive and significant impact on carbon emissions in both the long run and short run. Mesagan and Nwachukwu (2018) examine the determinant of environmental degradation using the ARDL bounds testing approach for 1981–2016. They generate environmental degradation index (GEDI) with the help of principal component analysis (PCA). They found financial development, energy consumption, trade, and income are significant determinants of environmental quality, while investment and urbanization are insignificant. Also, it finds no causal effect between capital investment, financial development, and environmental quality. Simultaneously, there was unidirectional causality from urbanization and income to environmental deprivation, and there is bidirectional causality between energy consumption and environmental degradation. Rafindadi (2016) examine the nexus between financial development, economic growth, energy consumption, trade openness, and CO_2 emissions in Nigeria. Using time series data from 1971 to 2011 and employed the ARDL bound co-integration approach, the Zivot-Andrew structural break unit root test, Bayer-Hanck co-integration approach, and VECM model well as impulse response test. He found financial development and trade openness stimulates energy demand and reduces CO_2emissions. Economic growth lowers energy demand but increases CO_2 emissions while energy consumption has significantly increased CO_2 emissions. He also found bidirectional causality between financial development and energy consumption and financial development and CO_2emissions. There was the existence of feedback effect between economic growth and CO_2 emissions.

Islam et al. (2013) also affirmed both long- and short-run relationships between financial development and CO_2 emissions in Malaysia. Boutabba (2014) found financial development aggravates CO_2 emissions in India. Jiang and Ma (2019) examined the nexus between financial development and carbon emissions, using a system generalized moment method for 155 countries by considering the countries' heterogeneous nature by dividing the sample into two subgroups: developed and emerging markets. The result indicated that financial developments significantly increase carbon emissions globally in emerging markets and developing countries. However, the effect on developed countries is insignificant. In the same vein, Abbasi and Riaz (2016) found that financial development is the main contributor to carbon dioxide emissions in small and emerging economies. Majeed and Mazhar (2019) examined the effects of financial development on environmental quality for a panel of 131 countries from 1971 to 2017. They found all financial development indicators: domestic credit to the private sector by banks, domestic credit to the private sector, and domestic credit provided by the financial sector significantly improve environmental quality by reducing the ecological footprint.

Comparatively, domestic credit to the private sector has a more substantial effect than other financial development measures and urbanization, while foreign direct investment (FDI), energy consumption, and GDP per capita worsen the environmental quality. Shahbaz et al., 2010 found that financial development is detrimental to environmental quality in Pakistan. Saleem et al. (2020) examined the role of GDP growth, sources of energy consumption, and other plausible hypothetical factors in CO_2 emissions for selected Asian countries for the period of 1980–2015 using fully modified OLS. They found lower-income economies do not support the EKC hypothesis during high-income and upper-middle-income economies' EKC hypothesis hold.

Aye and Edoja (2017) examined the effect of economic growth on CO_2 emission using dynamic panel threshold framework. Using panel data drawn from 31 developing countries, they found economic growth has a negative effect on CO_2 emission in the low growth countries but the positive effect in the high growth countries. Their finding does not support Environmental Kuznets Curve (EKC) hypothesis, but a *U*-shaped relationship was established. Also, energy consumption and population were also found to exert a positive and significant effect on CO_2 emission. Bekhet et al. (2017) established that financial development is liable for rising carbon emissions in Gulf Cooperation Council (GCC) countries except for United Arab Emirates (UAE). (Kahouli (2017) established a unidirectional causal relationship between financial development and CO_2 emissions in South Mediterranean economies (SMEs). However, Khan et al. (2018) found financial development reduces CO_2 emissions in Pakistan and Bangladesh but accentuated CO_2 emissions in India. Furthermore, a developed financial sector may bring down the cost of borrowing, promote investment in the clean energy sub-sector, and diminish CO_2 emissions (Muhammad et al. 2011).

Haseeb et al. (2018) hypothesize that financial development policies encourage progress (advanced technology), cut CO_2 emissions, and promote domestic production. Al-Mulali and Sab (2012) state that economic growth and energy consumption increases the aggregate demand; this will, in turn, increase demand for financial services, which could result in the financial sector setting up sound financial policies to control the amount of CO_2 emissions. Also, Zhang (2011) discourses that financial development will lead to financial inefficiency, which causes CO_2 emissions to rise. Haseeb et al. (2018) examined the effect of energy consumption and financial development for BRICS countries. They found energy consumption and financial developments are the main contributors to the carbon dioxide emissions and that the EKC hypothesis hold in BRICS economies. Siddique (2017) examined the impact of financial development and energy consumption on Pakistan's CO_2 emission from 1980 to 2015. He found energy consumption and financial development increased carbon dioxide emissions in Pakistan. Energy consumption and financial development enhance production and economic growth and increase carbon dioxide emissions (Siddique 2017).

However, studies that found financial development could play a positive role in curbing CO_2 emission; Khan et al. (2017) found bidirectional causality between financial development and CO_2 emissions in Asia. Riti et al. (2017) also reaffirmed financial development's role in reducing CO_2 emissions in 90 countries. Shahbaz et al. (2010) posit that financial development stimulates investment by risk-sharing. Tamazian and Rao (2010) employed the GMM approach to finding the effects of institutional, economic, and financial developments on CO_2 emissions for transitional economies. They found that these factors aid in lowering CO_2 emissions. Jalil and Feridun (2011) examined the impact of financial development, economic growth, and energy consumption on China's environmental pollution using aggregate data over the period 1953–2006. They found financial development reduces CO_2 emissions in China. Lee et al. (2015) examined the relationship between CO_2 emissions and financial development in OECD countries; they found that financial development can help EU countries to lower their CO_2 emissions and there is no evidence of EKC in EU countries. Xing et al. (2017) showed that financial development could improve China's carbon emissions condition, and this impact does not only reflect the regional difference. On the contrary, Omri et al. (2015) found a neutral relationship between financial development and CO_2 emissions in twelve MENA (the Middle East and North Africa) countries. Salahuddin et al. (2018) affirmed the neutral effect of financial development on CO_2 emissions in Kuwait and Islam et al. (2013), Jiang and Ma (2019), and Baloch et al. (2018) also reported a neutral relationship between financial instability and CO_2 emissions in Saudi Arabia. Recently, Acheampong (2019) investigates the direct and indirect effects of financial development on carbon emissions for a panel of 46 Sub-Saharan Africa countries over the period 2000–2015 using a dynamic system-GMM which investigated the impact of financial development on carbon emission intensity using the GMM approach throughout 1980–2015 using panel data of 83 countries. Pesaran et al. (2001) outlined that the overall financial development and its sub-measures reduce carbon emission intensity in developed and developing financial economies.

Methodology and data

Empirical model

Following the suggestion of Acheampong (2019) and Ang (2007), this research employed the autoregressive distributed lag method developed, whereas all other approaches required the variables in a time series regression equation are integrated of order one or at least of the same order, i.e., the variables are I(1), only ARDL or bound co-integration could be estimated irrespective of whether the underlying variables are I(0), I(1), or fractionally integrated, and fifth there is no need for lags length symmetry for the variables; in other words, each variable can take different lags depending on its relative importance in the mode (Pesaran et al. 2001).

Autoregressive distributive lags model

An autoregressive distributed lags model of order p and q is stated in general form ARDL (p, q) thus:

$$y_t = +\mu + \sum_{i=1}^{p} \gamma_i y_t + \sum_{j=1}^{q} \beta_j x_{t-j} + \varepsilon_t \quad (1)$$

where y_t is the dependent variable and x_t vectors of explained variables, all of which are stationary variables, μ is the intercept, and ε_t is the white noise error term. All variables are assumed to be endogenous. Using the lag operator L applied to each component of a vector, $L^k X_t = X_{t=k}$, it is convenient to define the lag polynomial $A(L)$ and vector polynomial $B(L)$

$$A(L)y_t = \mu + B(L)x_t + \varepsilon_t,$$

where $A(L) = 1 - \sum_{i=1}^{p} \gamma_i L^i$ and $B(L)y_t = \beta_o + \beta_1 L + \beta_2 L^2 + \ldots + \beta_q L^P$.

The general ARDL $(p, q_1, q_2, \ldots, p_k q_k)$ states as follows:

$$A(L) = \mu + A_1(L)y_{t-1} + B_1(L)x_{1t} + B_2(L)x_{2t} + \ldots + A_k(L)y_{t-k} B_k(L)x_{kt} + \varepsilon_t \quad (2)$$

If the values of x_t are treated as given, it is being uncorrelated with ε_t. OLS would be a consistent estimator. However, if x_t is simultaneously determined with y_t and $E(x_t, \varepsilon_t) \neq 0$, OLS would be an inconsistent estimator. As long as we can have assumed that the error term ε_t is a white noise process, or more generally, is stationary and independent of x_t, x_{t-1}, … and y_t, y_{t-1}, … the ARDL models can be estimated consistently with the ordinary least squares estimator. The long and short-run parameters could be estimated simultaneously.

To determine the effect of the dynamics of Eq. 1, we can invert Eq. 2 as a lag polynomial in y as:

$$y_t = \left(1+\gamma_1+\gamma_1^2+\ldots\right)\mu + \left(1+\gamma_1 L+\gamma_1^2 L^2+\ldots\right)\left(\beta_0 x_1+\beta_1 x_{t-1}+\varepsilon_t\right) \quad (3)$$

The current value of y depends on the current and all previous values of x and ε

$\frac{\partial y_t}{\partial x_t} = \beta_0$ is the multiplier impact

$\frac{\partial y_{t+1}}{\partial x_t} = \beta_1 + \gamma_1\ \beta_0$ one period effect

$\frac{\partial y_{t+2}}{\partial x_t} = \gamma_1\ \beta_1 + \gamma_1^2\beta_0$ second-period effect

$\frac{\beta_0+\beta_1}{1-\gamma_1}$ *if* $|\gamma_1|$ Long-run multiplier or long-run effect, this can generally be defined as:

$$\sum_{i=0}^{\infty}\gamma_i = \frac{B(L)}{A(L)} = C(L) = \frac{{}^q_i\beta}{1-{}^p_i\gamma_i}$$

where $C((L) = \frac{B(L)}{C(L)}$.

Assuming no shocks (disturbance) and stationary, the long-run relationship among the variables in the regression is:

$$y_{-} = \frac{\mu}{A(L)} + \frac{\beta_1(L)}{A(L)}X_{-1} + \frac{\beta_2(L)}{A(L)}X_{-2} + \ldots + \frac{\beta_k(L)}{A(L)}X_{-k}$$

where $\overline{X}$ and $\overline{Y}$ are the constant values of y and x_i.

The mean lag is $\left.\frac{A'(L)}{A(L)}\right|_{L=1}$

Now, we defined the error correction models (ECM) of Eq. 1 below.

ARD corrected model (error correction)

Given an autoregressive distributed lag model of order one ARDL (1,1) as follows:

$$ARDL\ \ (1,1):\quad y_t = \mu + \gamma y_{t-1} + \beta_0 x_t + \beta_1 x_{t-1} + \varepsilon_t \quad (4)$$

We subtract y_{t-1} from Eq. 4:

$$\Delta y_t = \mu + (\gamma-1)y_{t-1} + \beta_0 x_t + \beta_1 x_{t-1} + \varepsilon_t \quad (5)$$

We add/subtract $\beta_0 x_{t-1}$ to Eq. 5

$$\Delta y_t = \mu + (\gamma-1)y_{t-1} + \beta_0\Delta x_t + (\beta_0+\beta_1)x_{t-1} + \varepsilon_t \quad (6)$$

Then multiply $(\beta_0+\beta_1)x_{t-1}$ by $\frac{\gamma-1}{\gamma-1}$ we get:

$$\Delta y_t = \mu + (\gamma-1)(y_{t-1}-\phi x_{t-1}) + \beta_0\Delta x_t + \varepsilon_t \quad (7)$$

where $\varphi = \frac{\beta_0+\beta_1}{1-\gamma} = \frac{B(L)}{A(L)}$

$\frac{B(L)}{A(L)}$ is the long-run multiplier in our long-run model Eq. 1, the error correction model of ARDL(1,1)

$$\Delta y_t = \beta_0\Delta x_t + \gamma_{-}[y_{t-1}-(\mu_{-}+\varphi x_{t-1})] + \varepsilon_t \quad (8)$$

where $\overline{\mu} = \frac{\mu}{1-\gamma}, \overline{\gamma} = \gamma-1$, Δy_t consists of two components (plus disturbance): a short-run shock from Δx_t and feedback toward equilibrium, or equilibrium error correction. To see this, note that in equilibrium $y_t = y_{t-1} = \overline{y}$ and $x_t = x_{t-1} = \overline{x}$, so $\Delta y_t = 0$ and $\Delta x_t = 0$. Then the ECM is:

$$0 = \overline{\gamma}[y_{t-1}-(\overline{\mu}+\varnothing x_{t-1}\ )]$$

$$\overline{y} = \overline{\mu} + \varnothing\overline{x}$$

Therefore, $y_{t-1}-(\overline{\mu}+\varnothing x_{t-1}\ )$ represents the deviation from the equilibrium relationship.

$y = \overline{\mu} + \varnothing x.\beta_1 = (\gamma-1)$ is the marginal impact of this deviation on Δy_{t-1}.

Co-integration

The traditional method for estimating co-integrating relationships, such as Engle and Granger's (1987) and Johansen's (1991) single equation approaches, such as fully modified ordinary least squares or dynamic least squares required all variables in the regression to be I(1), or by pretesting the variables in order to established data generating process and determination of variables that are I(0) and those that are I(1).

An ARDL co-integrating regression model is obtained by transforming Eq. 1 into differences and substituting the long-run coefficients from Eq. 8:

$$\Delta y_t = -\sum_{i=1}^{p-1}\gamma_i^* y_{t-i} + \sum_{j=1}^{k}\sum_{i=1}^{q_j-1}\Delta X_{j,t-i}\beta_{j,i}^* - \rho y_{t-1} - \mu - \sum_{i=0}^{q_j-1}X_{j,t-i}\delta_j + \varepsilon_t \quad (9)$$

where

$$EC_{t-1} = y_t - \mu - \sum X_{j,i}\widehat{\Phi} = 1-\sum_{i=1}^{p}\widehat{\gamma}_{i,}\gamma^* = \sum_{m=i+1}^{p}\widehat{\gamma}_{i,}\beta_{j,i}^* = \sum_{i=0}^{q_j}\beta_{j,m}$$

The co-integrating relationship coefficients' standard error can be determined from the original regression's standard errors employing the delta method.

Bounds testing

Using the co-integrating relationship form in Eq. 9, Acheampong et al. (2020) describe a methodology for testing whether the autoregressive distributed lag model contains a level (long run) relationship between the dependent and independent variables. The bound test procedure transforms in Eq. 9 into the following representation:

$$\Delta y_t = -\sum_{i=1}^{p-1} \gamma_i^* y_{t-i} + \sum_{j=1}^{k} \sum_{i=1}^{q_j-1} \Delta X_{j,t-i} \beta_{j,i}^* - \rho y_{t-1} - \mu - \sum_{i=0}^{q_j-1} X_{j,t-i} \delta_j + \varepsilon_t \quad (10)$$

The test for the existence of level relationship (co-integration) is thus:

$$\rho = 0$$
$$\delta_1 = \delta_2 = \ldots = \delta_k = 0$$

These coefficient estimates used in a testing level relationship can be determined from a regression of Eq. (1 or estimated directly from a regression Eq. 10

The test statistic based on Eq. 10 has a different distribution under the null hypothesis of no level relationships (no co-integration) depending on whether the regressor is all I(0) or they are all I(1). In which case, the distribution is nonstandard regardless of integration order, Acheampong et al. (2020) and Pesaran et al. (2001) provide critical values for the case where all repessors are I(0) and where all regressors are I(1). They suggested using these critical values as bounds for the more typical cases where the regressor are combinations of I(0) and I(1).

The estimated F-statistics is compared with Pesaran tabulated critical values to reject or accept the null hypothesis. If F-statistic value is less than Pesaran tabulated critical lower bound I(0): there is no co-integration; if F-statistic value is greater than Pesaran tabulated critical upper bound I(1): there is co-integration and if F-statistic value falls within the lower bound I(0) and upper bound I(1): the test is inconclusive.

Specification of model

For capturing the impact of financial development on environmental quality, the following empirical model is formulated:

$$CO_{2t} = f\left(GDP_t, (GDP_t)^2, ENG_t, POP_t, FD_t\right)v \quad (11)$$

Equation 11 is transformed into natural logarithms to ensure uniformity in the unit of measure and allows us to interpret the estimated parameters in terms of elasticity:

$$InCO_{2t} = \gamma_0 + \gamma_1 InGDP_t + \gamma_2 In(GDP_t)^2 + \gamma_3 InENG_t + \gamma_4 InPOP_t + \gamma_5 InFD_t + V_t \quad (12)$$

where

$\mathbf{InCO_{2t}}$ is the natural log of carbon dioxide emission (a proxy for environmental quality) at time t, measured as metric tons per capita (Sources: World Development Indicators).

$\mathbf{InENG_t}$ is the natural log of fossil fuel consumption at time t, measured as the percentage of total energy consumption (kg of oil equivalent per capita) (Sources: World Development Indicators).

$\mathbf{InPOP_t}$ is the natural log of population density at time t, measured as no per square kilometer (Sources: World Development Indicators).

$\mathbf{InGDP_t}$ is the natural log of gross domestic product at time t, measured in 2000 constant US dollars (Sources: World Development Indicators).

$\mathbf{In(GDP_t)^2}$ is square of the natural log of gross domestic product (a proxy for economic growth) at time t, measured in 2000 constant US dollars (Sources: Author calculations).

$\mathbf{InFD_t}$ is the natural log of financial development indicator at time t, matured as the sum of financial access, depth, and efficiency indices (Sources: International Monetary Fund, Financial Development Index Database)

The expected sign from an estimated coefficient of the variables is as follows: $\gamma_1 \geq 0$, $\gamma_2 \geq 0$, $\gamma_3 \geq 0$, $\gamma_4 \geq 0$, $\gamma_5 \geq 0$; in other words, an increase in production, energy use, and population will increase carbon dioxide emission while squared of production will decrease carbon dioxide emission, and improvement in financial development in an economy could lead to an increase or decrease in carbon dioxide emission depending on the application or the area of usage.

The error correction version of the ARDL model is specified thus:

$$\Delta In(CP_{2t}) = \beta_1 + \sum_{i=1}^{n} \beta_2 InGDP_{t-i} + \sum_{i=1}^{n} \beta_3 In(GDP_{t-i})^2 + \sum_{i=1}^{n} \beta_4 CO_{2t-i} + \sum_{i=1}^{n} \beta_5 \Delta InENG_{t-i} + \sum_{i=1}^{n} \beta_6 \Delta InPOP_{t-i} + \sum_{i=1}^{n} \beta_7 \Delta InFD_{t-i} + \xi ECT_{t-i} + \varepsilon_t \ , \tag{13}$$

All variables are defined in Eq. 12: Δ is the difference operator and n is the maximum lag length, where ECT is the error correction term.

Bound test

$$InCO_{2t} = \alpha_0 + \sum_{i=1}^{j} \beta_1 CO_{2t-i} + \sum_{i=1}^{j} \beta_2 \Delta InGDP_{t-i} + \sum_{i=1}^{j} \beta_3 \Delta In(GDP_{t-i})^2 + \sum_{i=1}^{j} \beta_4 \Delta InENG_{t-i} + \sum_{i=1}^{j} \beta_5 \Delta InPOP_{t-i} + \sum_{i=1}^{j} \beta_6 \Delta InFD_{t-i} + \delta_1 CO_{2t-i} + \delta_2 \Delta InGDP_{t-i} + \delta_3 \Delta In(GDP_{t-i})^2 + \delta_4 InENG_{t-i} + \delta_5 InPOP_{t-i} + \delta_6 InFD_{t-i} + \varepsilon_t, \tag{14}$$

$$\Delta InGDP_{t-i} = \alpha_0 + \sum_{i=1}^{j} \beta_1 \Delta InGDP_{t-i} + \sum_{i=1}^{j} \beta_2 \Delta InCO_{2t-i} + \sum_{i=1}^{j} \beta_3 \Delta In(GDP_{t-i})^2 + \sum_{i=1}^{j} \beta_4 \Delta InENG_{t-i} + \sum_{i=1}^{j} \beta_5 \Delta InPOP_{t-i} + \sum_{i=1}^{j} \beta_6 \Delta InFD_{t-i} + \delta_1 \Delta InGDP_{t-i} + \delta_2 CO_{2t-i} + \delta_3 \Delta In(GDP_{t-i})^2 + \delta_4 InENG_{t-i} + \delta_5 InPOP_{t-i} + \delta_6 InFD_{t-i} + \varepsilon_t, \tag{15}$$

$$\Delta In(GDP_t)^2 = \alpha_0 + \sum_{i=1}^{j} \beta_1 \Delta In(GDP_{t-i})^2 + \sum_{i=1}^{j} \beta_2 \Delta InGDP_{t-i} + \sum_{i=1}^{j} \beta_3 CO_{2t-i} + \sum_{i=1}^{j} \beta_4 \Delta InENG_{t-i} + + \sum_{i=1}^{j} \beta_5 \Delta InPOP_{t-i} + \sum_{i=1}^{j} \beta_6 \Delta InFD_{t-i} + \delta_1 \Delta In(GDP_{t-i})^2 + \delta_2 \Delta InGDP_{t-i} + \delta_3 CO_{2t-i} + \delta_4 InENG_{t-i} + \delta_5 InPOP_{t-i} + \delta_6 InFD_{t-i} + \varepsilon_t, \tag{16}$$

$$\Delta InENG_t = \alpha_0 + \sum_{i=1}^{j} \beta_1 \Delta InENG_{t-i} + \sum_{i=1}^{j} \beta_2 \Delta In(GDP_{t-i})^2 + \sum_{i=1}^{j} \beta_3 \Delta InGDP_{t-i} + \sum_{i=1}^{j} \beta_4 \Delta InCO_{2t-i} + \sum_{i=1}^{j} \beta_5 \Delta InPOP_{t-i} + \sum_{i=1}^{j} \beta_6 \Delta InFD_{t-i} + \delta_1 InENG_{t-i} + \delta_2 \Delta In(GDP_{t-i})^2 + \delta_3 \Delta InGDP_{t-i} + \delta_4 CO_{2t-i} + \delta_5 InPOP_{t-i} + \delta_6 InFD_{t-i} + \varepsilon_t, \tag{17}$$

$$\Delta InPOP_t = \alpha_0 + \sum_{i=1}^{j} \beta_1 \Delta InPOP_{t-i} + \sum_{i=1}^{j} \beta_2 \Delta InENG_{t-i} + \sum_{i=1}^{j} \beta_3 \Delta In(GDP_{t-i})^2 + \sum_{i=1}^{j} \beta_4 \Delta InGDP_{t-i} + \sum_{i=1}^{j} \beta_5 CO_{2t-i} + \sum_{i=1}^{j} \beta_6 \Delta InFD_{t-i} + \delta_1 InPOP_{t-i} + \delta_2 InENG_{t-i} + \delta_3 \Delta In(GDP_{t-i})^2 + \delta_4 \Delta InGDP_{t-i} + \delta_5 CO_{2t-i} + \delta_6 InFD_{t-i} + \varepsilon_t, \tag{18}$$

$$\Delta InFD_t = \alpha_0 + \sum_{i=1}^{j} \beta_1 \Delta InFD_{t-i} + \sum_{i=1}^{j} \beta_2 \Delta InPOP_{t-i} + \sum_{i=1}^{j} \beta_3 \Delta InENG_{t-i} + \sum_{i=1}^{j} \beta_4 \Delta In(GDP_{t-i})^2 + \sum_{i=1}^{j} \beta_5 \Delta InGDP_{t-i} + \sum_{i=1}^{j} \beta_6 CO_{2t-i} + \delta_1 InFD_{t-i} + \delta_2 InPOP_{t-i} + \delta_3 InENG_{t-i} + \delta_4 \Delta In(GDP_{t-i})^2 + \delta_5 \Delta InGDP_{t-i} + \delta_6 CO_{2t-it-i} + \varepsilon_t, \tag{19}$$

$H_0 = \delta_1 = \delta_2 = \delta_3 = \delta_4 = \delta_5 = 0$ is no level relationship vs. the alternative hypothesis of co-integration: $H_0 = \delta_1 = \delta_2 = \delta_3 = \delta_4 = \delta_5 \neq 0$; level relationship exists.

Data

Our study investigates the impact of financial development on environmental quality, the collision of renewable energy utilization, population growth, economic growth, and financial development on Malaysia's environmental quality from 1987 to 2020. This research employed statistical tools to discover the dynamic linkages between financial development on environmental quality. Data on the desired variables have been collected from starting published world growth display on the World Bank website[1]. These variables are financial development, renewable energy utilization taken as (proportion of whole ultimate power/per year), population growth/per year, GDP per capita (annual growth percent), and carbon dioxide emission (metric tons per capita) in the respective country. Furthermore, financial development indices are computed from depth, access, and efficiency, using these as a proxy for financial development in the country from 1987 to 2020. Moreover, all results reported in this research are carried out on R-environment, a user-friendly statistical analysis tool with the help of PLM package available online under https://cran.r-project.org/web/packages/plm/vignettes/plmpackage.html.

Empirical results and discussion

Exploration work of the data was done with the help of summary statistics presented in Table 1; energy use has the highest means while the gross domestic product has the lowest mean value of all the variables. In the same vein, energy use has the highest minimum and maximum values while the gross domestic product has the least minimum and maximum values. However, the standard deviation, which measured a variable's variability, shows that carbon dioxide emission was the most volatile while financial development was the least volatile. Furthermore, carbon dioxide emission, financial development, and population were negatively skewed, while gross domestic product and energy use were positively skewed. All variables were non normally distributed as the Jar-Bera test's probability values were greater than 0.05 for critical values at a 5% level of significance.

Next, we examined the stationarity of the variables with the help of the unit root test. The unit root test result is displayed in Table 2, indicating that all variables were not stationary at level except population, and they were different stationery. This implied that the variables were integrated of order one, i.e., I(1) except population, which is integrated of order zero, i.e., I(0) variable. We proceed with our co-integration analysis using the ARDL method.

Lag length selection

The first step in estimating the ARDL model is determining the optimal lag length for each variable's variable. Using traditional unrestricted VAR procedures to determine symmetry lags length for all variables as in other autoregressive models does not provide optimal estimates for the ARDL model.

In Table 3, the result of lag lengths selection criteria of our model using four information criteria. The Akaike information criteria (AIC), Schwarz information criteria (SIC), Hannan-Quinn criteria (HQC), and adjusted *R*-squared (AR) provide the same lag lengths for individual variables.

[1] https://data.worldbank.org/indicator.

Table 1 Summary statistics

Variables	Statistics						
	Mean	Std. dev.	Maximum	Minimum	Skewness	Kurtosis	Jar-Bera
InCO_2	11.09	0.38	11.57	10.47	−0.34	1.59	3.47
InFD	2.97	0.08	3.13	2.76	−0.41	2.59	0.34
InGDP	2.58	0.24	3.06	2.22	0.71	2.28	3.57
InPOP	8.17	2.20	11.39	4.97	−0.08	1.59	2.85
InENG	18.56	0.25	18.99	18.13	0.01	1.82	1.97

However, adjusted *R*-squared (AR) showed error term has the first-order autocorrelation. Since the diagnostic test of AR fails for one of the OLS assumptions, we proceed to estimate co-integration among these variables with the selected ARDL (3, 0, 2, 3, 2, 2) model. And the underlines diagnostic test for these information criteria shows that these models are correctly specified; there is no first and second-order autocorrelation (serial correlation), no heteroscedasticity (homoscedasticity), no ARCH effect in residual, and are normally distributed. Hence, the selected model is suitable for inference. As stated by Acheampong et al. (2020), the serial correlation has consequences on a co-integration result, hence assessing diagnostics tests before embarking on the selected model's co-integration estimate.

The autoregressive distributed lag bound test

The next step after appropriate lags has been determined is the estimate of the ARDL bound co-integration test. The test was carried out by estimating Eq. 14 and the normalization method for Eqs. 15–19 by taken each variable as a dependent variable as advocated by Acheampong et al. (2020) using selected lags 3, 0, 2, 3, 2, 2, and estimated autoregressive distributed lag model in Table 4.

This test involved restricting the first lagged level for all variables using the *F*-statistic through the Wald test (bound test) to determine the joint significance level. Table 4 revealed that carbon dioxide emission (CO_2), financial development, gross domestic product (GDP), squared gross domestic product (GDP^2), population (POP), and energy use (ENG) were jointly co-integrated (long-run relationship). The *F*-statistic from the bound test for

$$F_{CO2}\left(CO_2|\ GDP, GDP^2, FD, POP, ENG\right) = 5.76,$$
$$F_{GDP}\left(GDP\ |\ CO_2, GDP^2, FD, POP, ENG\right) = 46.81,$$
$$F_{GDP2}\left(GDP^2|\ GDP, CO_2, FD, POP, ENG\right) = 18.46,$$
$$F_{FD}\left(FD\ |\ GDP^2, GDP, CO^2, POP, ENG\right) = 6.59,$$
$$F_{POP}\left(POP\ |\ FD\ GDP^2, GDP, CO_2, ENG\right) = 77.30,$$

and

$$F_{ENG}\left(ENG\ |\ POP, FD, GDP^2, GDP, CO_2\right) = 5.43$$

were greater than the upper bound of 3.79 Pesaran critical value 5% significance level, and five independent variables ($k = 5$) with no constant and trend, case I. Hence, these variables have a long-run relationship; that is, they commove in the long run. After the variables co-integrated, there must be an error correction model to determine the speed of adjustment in the short run when they might drift apart.

Table 2 Unit root test

		Variables				
		InCO_2	InFID	InGDP	InPOP	InENG
Level	ADF	−1.7946	−2.1391	−1.4287	−5.6923	−2.6569
		(0.6844)	(0.5067)	(0.8334)	(0.0005)	(0.0921)
	Critical value	−3.5539	−3.5539	−3.5539	−3.5539	−3.5539
	Result	I(1)	I(1)	I(1)	I(1)	I(1)
		ΔInCO_2	ΔInFID	ΔInGDP	ΔInPOP	ΔInENG
First difference	ADF	−5.5568	5.2361	−3.1951	–	−6.0845
		(0.0001)	(0.0002)	(0.0296)		(0.0000)
	Critical value	−2.9561	−2.9561	−2.9561	−2.9561	−2.9561
	Result	I(0)	I(0)	I(0)	I(0)	I(0)

Values in parentheses are MacKinnon (1996) one-sided *p*-values. Critical values are obtained from the Augmented Dickey-Fuller test result

Table 3 Model selection criteria

Information criteria	Model diagnostic check ARDL(3, 0, 2, 3, 2, 2)					
	χ^2_{FF}	χ^2_{H}	$\chi^2_{ARCH(1)}$	$\chi^2_{SC(1)}$	$\chi^2_{SC(2)}$	χ^2_{N}
Akaike information criteria (AIC)	0.1015	0.8375	0.3563	0.7691	0.2984	0.8765
Schwarz information criteria (SIC)	0.1015	0.8375	0.3563	0.6235	= 0.4773	0.8765
Hannan-Quinn criteria (HQC)	0.1015	0.8375	0.3563	0.5733	= 0.2984	0.8765
Adjusted R-squared (AR)	0.1015	0.8375	0.3563	0.0492	= 0.2984	0.8765

$\chi^2_{FF}, \chi^2_{H}, \chi_{ARCH}(1)^2, \chi^2_{SC(1)}, \chi^2_{SC(2)}, \chi^2_{N}$ are Lagrange multiplier statistic test for functional form misspecification, residual heteroscedasticity, ARCH effect, autocorrelation (serial correlation), and non-normal error, respectively

Having found that the variables are co-integrated, Table 5 presents the estimated result of a short-run model, while the long-run result is presented in Table 6. Financial development impacted positively on environmental quality in Malaysia. A 1% increase in financial development will lead to a 0.78% and 1.33% fall in Malaysia's environmental quality, which is statistically significant in both the short and long run. This result is consistent with Ali et al. (2019) and Mesagan and Nwachukwu (2018) for Nigeria. These studies employed the ARDL approach and covered the period of 1971 to 2010, 1981–2018, and 1971–2011 respectively. Our findings confirmed their results. However, we employed a broader financial development measure (depth, access, and efficiency as a proxy of financial development indices). Our result is also consistent with Sadorsky (2011) and Zhang (2011) for China, Emerging Economies, and Central and Eastern European Frontier Economies. However, our result contradicted Haseeb et al. (2018), where they found financial development improved environmental quality. This result is no surprise, as more credit advances to businesses are geared towards installing new plants and expanding activities against the adoption of new technology and environmentally friendly or enhancing environmental quality in Malaysia. Adopting environmentally friendly/energy-saving consumer products is very low because old and outdated electronics, used cars, etc. are among the most patronized products by Malaysian consumers.

An increase in population leads to an increase in carbon dioxide emission in the short run. However, the first lag of population leads to a reduction in carbon emission in the short run. For instance, a 1% change in population will lead to a 316.5% increase in CO_2 emission in the short run, while 1% increase in the first lags of the population will lead to a 421.4% reduction in CO_2 in Malaysia. Also, the population has a positive and significant influence on environmental quality in the long run; a 1% t increase in population will lead to a 4.85% fall in environmental quality.

Furthermore, the gross domestic product has a significant positive impact on the environment; 1% increase in the gross domestic product will lead to an increase of 1.19% and 1.59% environmental degradation in the short run and long run, respectively. However, the squared gross domestic product has a significant negative impact on environmental quality. A 1% increase in the squared gross domestic product contributes

Table 4 Bound co-integration test

Dependent variables	No. variables	F-statistics	Decision
$F_{CO2}(CO_2$ GDP, GDP^2,FD, POP, ENG)	5	5.76	Co-integration
F_{GDP}(GDP CO_2, GDP^2,FD, POP, ENG)	5	46.81	Co-integration
$F_{GDP}{}^2(GDP^2$ GDP, CO_2,FD, POP, ENG)	5	18.46	Co-integration
F_{FD}(FD GDP^2, GDP,CO2, POP, ENG)	5	6.59	Co-integration
F_{POP}(POP FD, GDP2,GDP,CO_2, ENG)	5	77.30	Co-integration
F_{ENG}(ENG POP, FD,GDP2,GDP,CO_2)	5	5.43	Co-integration
Pesaran et al. (2001)	Significance level		
Critical value	10 %	5%	1%
I(0) bound	2.27	2.63	3.42
I(1) bound	3.35	3.79	4.69

Table 5 Parsimonious estimation for short-run model

Variables	Coefficient	Standard error	t-statistics	P-values
Constant	3.05	1.02	2.98	0.008
D(LCO$_2$(-1))	1.33	0.34	3.89	0.001
D(LCO$_2$(-2))	0.19	0.17	1.17	0.262
D(LGDP)	1.19	0.75	1.59	0.132
D(LGDP^2)	−0.13	0.05	−2.74	0.014
D(LGDP^2(-1))	−0.05	0.03	−2.08	0.053
D(LGDP^2(-2))	−0.05	0.02	−2.44	0.026
D(LFD)	0.78	0.28	2.73	0.015
D(LFD(-1))	−0.59	0.34	−1.73	0.105
D(LFD(-2))	−0.43	0.29	−1.45	0.171
D(LENG)	1.61	0.36	4.43	0.000
D(LENG(-1))	-0.61	0.47	−1.29	0.219
D(LPOP)	316.50	174.08	1.84	0.085
D(LPOP(-1))	−421.44	161.27	−2.69	0.016
ECM(-1)	-0.218	0.084	−2.58	0.002
R-square Adj. *R*-square *F*-statistic sDW	0.7864 0.6036 4.2372 (0.0000) 2.6081			

−0.13% and −0.08% decrease in environmental quality in the short and long run. Having found that squared gross domestic product has a negative impact on CO_2 emission, it implied that environmental carbon Kuznets curve (ECKC) hold in Malaysia. Our result is consistent with findings by Kahouli (2017). Finally, energy use has a significant positive impact on environmental quality, a 1% increase in energy use will contribute 1.61% and 1.09% fall in environmental quality in the short and long run, respectively. It implied that as we increase energy consumption, it contributes significantly to environmental degradation both in the short and long run. This result is in line with Tamazian and Rao (2010) for

Table 6 Parsimonious estimations for long-run model

Variables	Coefficient	Standard error	t-statistics	P-values
Constant	99.94	54.52	1.84	0.0783
LGDP	1.52	0.54	2.86	0.0437
LGDP^2	−0.09	0.04	−2.69	0.0211
LFD	1.38	0.33	4.27	0.0049
LENGs	1.11	0.31	3.31	0.0180
LPOP	−4.85	1.14	4.40	0.0125
R-square Adj. *R*-square *F*-statistic DW	0.8700 0.83780 27.84 (0.0000) 2.0874			

Pakistan and with Haseeb et al. (2018) for BRICS countries. Worthy of note is the additive impact of past carbon emissions on society's current emission state. A 1% increase in past CO_2 emissions will contribute to a 1.33% increase in Malaysia's current environmental degradation.

The error correction term [ECT(-1)] is negatively and statistically significant, reinforcing the variable's earlier co-integration relationship. This means any disequilibrium in the previous period, 21.8% are corrected each year, all things being equal. Also, Tables 5 and 6 showed adj. independent variables explain R-square 60% and 83% in short and long-run variation in the dependent variable. The joint significance given by *F*-statistics 4.23 *p*-value (0.00) and 26.83 (0.00) in the short and long run is that collectively the independent variables are a significant determinant of the dependent variable.

Diagnostic testing

The diagnostic test result for the functional form of the misspecification test is presented in Table 7. The analysis shows that the model is free from the function from misspecification bias, the error variance is Homoscedastic, no ARCH effect in the model, no first and second-order auto-correlation (serial correlation) in residual and residuals were normally distributed, and white noise in both short and long run as displayed.

Also, the coefficient stability test shows that both short- and long-run coefficients were stable. The stability test results are graphically presented under Figs. 2 and 3 below. The green curve represents the CUSUM and CUSUM squared test curves, whereas the dotted line represents the lower and upper critical bound of 5% significance level.

Table 7 Diagnostic test results of short and long run

sLagrange multiplier test statistics	Model type	
	Short run	Long run
Non-normal error, χ^2_N	0.6993 (0.77049)	1.5742 (0.6 951)s
Autocorrelation (serial correlation), $\chi^2_{SC(1)}s$	2.2256 (0.1565)	0.1211 (0.7203)
Autocorrelation (serial correlation), $\chi^2_{SC(2)}s$	2.7813 (0.0961)	1.5651 (0.2296)
ARCH effect, $\chi^2_{ARCH(1)}$	0.6822 (0.70142)	0.0651 (0.78002)
Residual heteroscedasticity, χ^2_H	2.1881 (0.0676)	0.4090 (0.8382)
Functional form specification, $\chi^2_{FF}s$	s 0.3120 (0.7593)	0.3242 (0 0.7485)

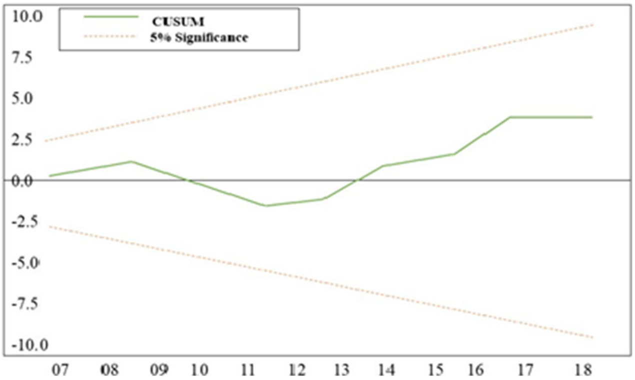

Fig. 2 CUSUM coefficient stability graph

The coefficients'stability is reflected from both the graphs, as the CUSUM and CUSUM squared curve operates within the lower and upper bound of 5% level of significance.

Short-run causality analysis

For determining the short-run causality from independent variables to dependent variables, the test was conducted on an economical result obtained from the short-run model by imposing joint restriction on change and lags of each variable via *F*-statistic Wald test; with null hypothesis, the variables are jointly zero. Table 8 presents short-run causality among variables in the carbon dioxide emission (CO_2) model. Financial development, economic growth, energy use, and population cause carbon dioxide emission in the short run.

Conclusion and policy implications

The role of environmental quality on sustainable growth and development of the Malaysian economy cannot be overemphasized in policy formulation and implementation and its implication on the economy's sustainability. This research examined the impacts of financial development on Malaysia's environmental quality from 1987 to 2020. The study employed an autoregressive distributed lag method to

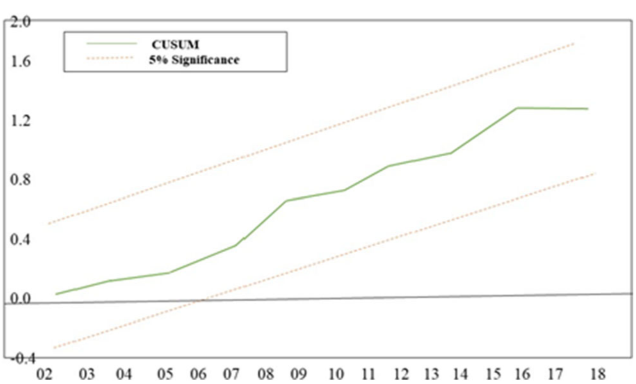

Fig. 3 CUSUM Squared coefficient stability graph

Table 8 Short-run causality analysis

Direction	*F*-statistics	*P*-value	Decision
Financial development → CO_2	10.5657	0.0071	Causality exist
Economic growth → CO_2	7.3931	0.0030	Causality exist
Population → CO_2	8.4721	0.0006	Causality exist
Energy use → CO_2	14.623	0.0005	Causality exist
Squared economic growth → CO_2	11.7301	0.0085	Causality exist

examined the level relationship (long run) among the variable of interest: carbon dioxide emission (CO_2), financial development, energy usage, economic growth, squared economic growth, and population.

Financial development, population, economic growth, and energy usage are significant positive contributors to environmental degradation in Malaysia's short and long run, while squared economic growth significantly enhances ecological quality in both the short and long run. Environmental carbon Kuznets curve (ECKC) hold in Malaysia. Thus, our research findings are different from Acheampong's (2019) conclusions who rejected the ECKC hypothesis for sub-Saharan Africa countries. The result further shows that this variable had a level relationship (long run), confirmed by the error correction term's negative and statistical significance. That is any disequilibrium in the previous period, 21.8% is corrected in 1 year. Also, there is a short-run causal effect from financial development, economic growth, squared economic growth, energy usage, and population to carbon dioxide emission.

Policy implications

Finally, this research contributes to knowledge, has important policy implications, and presents future researchers' lessons. The result emphasizes the need to channel financial resources toward clean energy projects and adopt new technology to improve carbon footprint to improve environmental quality. The government should take the lead in the adoption of renewable energy technology and decommissioning of nonrenewable technology aggressively in Malaysia, and adoption of population policy that aims at curbing explosive population growth of the past decades. This research recommends that while financial development delays the environment's quality, financial institutions should boost industries to participate in environmentally friendly projects and provide credit at lower costs to firms committed to investing in environmental sustainability projects. The policy implications apply to Malaysia and are prolonged to other developed and developing economies across the globe. In the future, this research could extend this research by investigating the institutional context through which financial development and foreign direct investment impact environmental quality in developed countries.

Abbreviations ECKC, environmental carbon Kuznets curve; CO_2, carbon dioxide emission; GDP, gross domestic product; GDP^2, squared gross domestic product; POP, population; ENG, energy use; GMM, generalized method of moment; ADL, autoregressive distributive lags model; GEDI, generate environmental degradation index; PCA, principal component analysis

Code availability All the results reported in this research are carried out in R-studio environment

Data availability The data used in this research is available at https://data.worldbank.org/indicator.

Declarations

Conflict of interest The authors declare no competing interests.

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