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ARTICLE

An econometric evaluation of the effects of economic growth, energy use, and agricultural value added on carbon dioxide emissions in Vietnam

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Abstract
Global climate change caused by Greenhouse Gases (GHGs), particularly carbon dioxide (CO_2) emissions, poses incomparable threats to the environment, development and sustainability. Vietnam is experiencing continuous economic growth and agricultural advancement, which causes higher energy consumption and CO_2 emissions. Understanding Vietnam's sensitivity to climate change is becoming more crucial for governments trying to reconcile climate change mitigation and sustainable development. Analyzing pollution-development trade-offs can help minimize environmental degradation in Vietnam. Therefore, the present study empirically investigated the nexus between economic growth, energy use, agricultural added value and CO_2 emissions in Vietnam. To investigate the short-run and long-run relationships between the variables, this study employed the autoregressive distributed lag (ARDL) technique and the Vector Error Correction Model (VECM) using the time series data from 1984 to 2020 for Vietnam. The empirical findings indicated that economic growth and energy use trigger environmental degradation by increasing CO_2 emissions, whereas enhancing agricultural added value improves Vietnam's environmental quality by reducing CO_2 emissions in both the long-run and short-run. The estimated results are robust compared with alternative estimators such as dynamic ordinary least squares (DOLS), fully modified least squares (FMOLS), and canonical cointegrating regression (CCR). This research contributes to the existing literature by shedding light on the potential of agricultural added value to reduce emissions in Vietnam and provides policy recommendations in areas of low-carbon economy, promoting renewable energy, and sustainable agriculture that can reduce CO_2 emissions in Vietnam.

Keywords Environmental degradation · CO_2 emissions · Economic growth · Energy use · Agriculture · Sustainability

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1 Introduction

Global climate change is a burning issue due to the atmospheric concentrations of GHGs dominated by CO_2 which is mostly released by human-caused activities such as fossil fuel combustion and deforestation (Raihan et al. 2018, 2021a, 2022a; Jaafar et al. 2020). The continuous increase in CO_2 emissions is expected to have massive ramifications for the global climate system, with catastrophic consequences affecting all segments of society (Raihan et al. 2019, 2022b; Isfat and Raihan 2022). Therefore, reducing CO_2 emissions and increasing environmental quality has become a global concern to ensure sustainable development and mitigate the negative effects of climate change (Ali et al. 2022; Raihan et al. 2021b, 2022c; Raihan and Said 2022). Consequently, determining the main determinants of CO_2 is essential to increasing environmental quality. If the functional relationship between natural resources and modern development processes cannot be prevented, environmental damage will unavoidably occur. Such issues are more common in developing countries like Vietnam, where economic growth, energy security, agricultural value added, and environmental sustainability are simultaneously important (Shahbaz et al. 2019).

Vietnam is a developing country that has had significant economic progress during the last four decades (Nguyen et al. 2021). Vietnam has also devised techniques for achieving economic growth that is compatible with long-term development. Vietnam has ratified international conventions to adapt to climate change and reduce carbon emissions, including the Kyoto Protocol and the Paris Agreement. In its current Intended National Determined Contributions (INDC), Vietnam has acknowledged that it will reduce GHG emissions by eight percent using domestic resources by 2030 compared to a business-as-usual scenario. At the same time, Vietnam is grappling with major environmental issues. Overall understanding Vietnam's vulnerability to climate change is becoming increasingly important for policymakers seeking to strike a balance between policies aimed at mitigating climate change and achieving sustainable development, as well as implementing measures that achieve both. The trade-off between pollution and development is the most difficult aspect of achieving this dual goal at the same time. A significant question that arises is how Vietnam might reduce CO_2 emissions, and this question can be answered by examining the country's environmental variables.

Vietnam has transitioned from a low-income country to a lower-middle-income country as one of the world's fastest-growing transitional economies (Nguyen et al. 2021). Vietnam's gross domestic product (GDP) increased nearly nine times from 30 billion USD in 1986 to 259 billion USD in 2020 (World Bank 2022). It is the 2nd fastest-growing economy in Southeast Asia and 23rd in the world with an annual GDP growth rate of 7% in 2019 (World Bank 2022). However, Vietnam's impressive economic progress is linked to an increase in energy use, which has resulted in a slew of environmental issues (Al-Mulali et al. 2015; Tang and Tan 2015; Phong et al. 2018; Shahbaz et al. 2019; Nguyen et al. 2021). The fact that Vietnam's economy is based on fossil fuels such as coal and oil is the primary source of the country's increasing environmental issues (Shahbaz et al. 2019; Nguyen et al. 2021). The increase in fossil fuel energy use leads to a substantial rise in CO_2 emissions (Raihan et al. 2022d). Since 2018, Vietnam's CO_2 emissions per capita have surpassed the global average (Nguyen et al. 2021). Therefore, the country is highly concerned about the growing emission intensity, especially from the energy sector. Hence, climate change challenges have heightened the debate over the adoption of energy conservation regulations in Vietnam, as well as the necessity to comprehend the nexus between economic growth, energy consumption, and CO_2 emissions.

Agriculture is one of the primary drivers of environmental degradation (Raihan et al. 2023a). Agriculture is linked to CO_2 emissions and is considered ultrasensitive to climate change (Raihan and Tuspekova 2022a). Agriculture, forestry, and other land use (AFOLU) and land use, land-use change and forestry (LULUCF) activities account for roughly one-fifth of global yearly CO_2 emissions, making it the second-largest source of CO_2 emissions and a key contributor to global climate change (IPCC 2014). Vietnam's agriculture sector has advanced tremendously over the last quarter-century. It is a major producer and exporter of a variety of agricultural products, including coffee, peanuts, and rice. Furthermore, agriculture has been the leading employment in Vietnam across all economic sectors, employing more than 18.8 million Vietnamese in 2019 (Nguyen et al. 2021). However, improving agricultural value added, as well as environmental quality, are both necessary for long-term development. Increased agricultural value added decreases poverty, increases income distribution, food security, and promotes economic development (Raihan et al. 2023b). Agricultural value added also benefits the environment, according to economic research (Shahbaz et al. 2019; Prastiyo et al. 2020). Agricultural value added is linked to economic growth, which promotes demand for cleaner environments, commodities, and services, as well as the government's ability to enforce environmental legislation (Borlaug 2007). The argument that agricultural value added opposes the spread of cropland into forest areas follows the same logic. This encourages forest protection while also reducing pollution and environmental deterioration (Burney et al. 2010). Agricultural value added, on the other hand, has long been seen to contribute to environmental deterioration, and this alarm is growing. According to a study published by the FAO (2017), about half of the worldwide forest cover has been encroached upon, groundwater supplies have been depleted, and biodiversity has been destroyed as a result of increased food production and economic growth. According to the same research, the annual combustion of fossil fuels in agriculture puts billions of tons of GHGs into the atmosphere, contributing to global warming and climate change (Wang et al. 2020a). As a result, research on the relationship between agricultural value added and environmental degradation is critical for the development of successful sustainable agriculture policies.

Over the last three decades, the determining factors of environmental degradation have been examined in several studies. Grossman and Krueger's (1991) analysis sparked a debate over whether there is a relationship between environmental degradation and economic advancement. This study influenced many scholars, and empirical research on the environmental consequences of economic expansion flourished as a result. As a result, various studies employing time series data examined the associations between environmental pollution indicators such as CO_2 emissions and economic development (Adebayo et al. 2020; Begum et al. 2020; Raihan 2023a). However, there has been very little research in Vietnam on the interaction of CO_2 emissions and environmental variables, even though it has become a hot topic among contemporary researchers worldwide. Therefore, the present study aims to fill up this literature gap by using econometric approaches to explore the nexus between economic growth, energy use, agricultural value added, and CO_2 emissions in Vietnam. This research is expected to contribute to the recent literature and policymaking in Vietnam in three ways. Firstly, the novelty of this research is the evaluation of the impact of agricultural value added on CO_2 emissions in Vietnam which is a ground-breaking attempt to reveal the nexus between agricultural value added and CO_2 emissions. Secondly, several diagnostic tests, unit root tests (ADF, DF-GLS, P-P), cointegration tests (ARDL bounds test, Johansen cointegration test, Engle-Granger cointegration test), and cointegration regression models (ARDL, DOLS, FMOLS, CCR) were employed to verify the precision of the results. In addition, the Toda-Yamamoto causality test was utilized to capture the causal linkage between the variables. Lastly, the study's findings would provide policymakers with more comprehensive and useful information for developing successful policies in the areas of low-carbon economy, promoting renewable energy, and sustainable agriculture that would reduce CO_2 emissions in Vietnam. In addition, the findings from this investigation are useful for environmental policy evaluation and further policy formation to prepare Vietnam for a 1.5 °C world by strengthening policy and action plan to reduce the climate change impacts thereby ensuring sustainable development and environmental quality in the long term. This study encourages examining the dynamic impacts of socio-economic and environmental factors on environmental pollution in developing countries with rapid economic growth to establish a balance between sustainable development and emissions reduction. This study's outcome could provide suggestions and recommendations to other developing countries aiming at building successful strategies to achieve environmental sustainability while strengthening climate change mitigation and adaptation strategies.

2 Literature review

The association between economic growth, energy usage, and CO_2 emissions has been thoroughly documented in empirical investigations. A variety of research including numerous countries, factors, and methodologies were considered. Begum et al. (2015) revealed the positive effects of economic growth and energy use on CO_2 emissions by employing the ARDL approach and DOLS technique for Malaysia using the data over 1970–2009. Using the ARDL estimator for India spanning 1971–2011, Sehrawat et al. (2015) found that economic growth and energy use increases CO_2 emissions. Liu and Bae (2018) revealed the positive effects of economic growth and energy consumption on CO_2 emissions in China from 1970 to 2015 by applying the ARDL method. Using the ARDL estimator for Kazakhstan spanning 1980–2011, Akbota and Baek (2018) found that economic growth and energy use increases CO_2 emissions. By employing an ARDL estimator using yearly data between 1971 and 2014, Ahmed et al. (2019) reported that economic growth and energy use trigger CO_2 emissions in Indonesia. By applying ARDL, FMOLS, and DOLS estimators using the yearly data spanning between 1971 and 2016, Adebayo (2020) found that economic growth and energy use influence CO_2 emissions positively in Mexico. Kirikkaleli and Kalmaz (2020) found positive impacts of economic growth and energy use on CO_2 emissions in Turkey throughout 1960–2016 by utilizing FMOLS and DOLS techniques. Odugbesan and Adebayo (2020) found the positive impacts of economic growth and energy consumption on CO_2 emissions in Nigeria by utilizing the yearly data spanning from 1981 to 2016 employing ARDL, FMOLS, and DOLS techniques. By employing the ARDL approach, Nondo and Kahsai (2020) revealed the positive effects of economic growth and energy intensity on CO_2 emissions in South Africa from 1970 to 2016. Adebayo and Kalmaz (2021) used ARDL, FMOLS, and DOLS methods to uncover a positive interaction of economic growth and energy use with CO_2 emissions in Egypt by using the data from 1971 to 2014. In addition, Islam et al. (2021) revealed the positive effects of economic growth, and energy use on CO_2 emissions in Bangladesh by utilizing the ARDL approach using the data over 1970–2009. By employing ARDL, quantile regression, FMOLS, CCR, and DOLS models using yearly data between 1970 and 2016 for Portugal, Leitão (2021) reported that energy consumption is directly associated with climate change and the environment's damage by increasing CO_2 emissions while economic growth seems to promote sustainable development practices in the long run.

Furthermore, a number of studies reported the positive effects of economic growth and energy use on CO_2 emissions from a group of countries. By utilizing FMOLS and DOLS estimators using the data from 1971 to 2014, Vo et al. (2019) revealed that the level of CO_2 emissions is positively associated with economic growth and energy use in ASEAN nations. By using time series data over 1985–2013 for 20 African countries, Raheem and Ogebe (2017) found that economic growth and energy use increases CO_2 emissions. Adebayo et al. (2020) found positive interconnection of economic growth and energy use on CO_2 emissions by utilizing the ARDL model for MINT countries using the time coverage from 1980 to 2018. Zmami and Ben-Salha (2020) reported the positive impacts of economic growth and energy use on CO_2 emissions in GCC countries between 1980 and 2017 using the STIRPAT and ARDL approaches. Wang et al. (2020b) utilized the DSUR method using data covering the years 1990 to 2014 for APEC countries. Wang et al. (2020b) reported that energy intensity and economic growth enhance the level of CO_2 emissions. Teng et al. (2021) reported that economic growth and energy use positively influence CO_2 emissions in OECD countries.

The influence of agriculture on environmental degradation has been a frequent issue of controversy throughout the previous decade. Various econometric methodologies have been used in recent research to examine the impact of agriculture on environmental deterioration. By utilizing the ARDL approach using data from 1968 to 2010, Dogan (2016) reported that CO_2 emissions in Turkey are positively associated with economic growth and negatively associated with agricultural production. Prastiyo et al. (2020) found positive impacts of economic growth on CO_2 emissions, but negative impacts of agriculture value added on CO_2 emissions utilizing the ARDL technique for Indonesia using the data over 1970–2015. Liu et al. (2017) employed the ARDL model to uncover a positive effect of economic growth on CO_2 emissions and a negative influence of agricultural value added on CO_2 emissions in ASEAN countries using data over the span time of 1970–2013. Jebli and Youssef (2017) reported that an increase in GDP influences CO_2 emissions, but a rise up in agricultural value added decreases CO_2 emissions in North African countries throughout 1980–2011 by utilizing OLS, FMOLS, and DOLS techniques. By employing the ARDL model using the data for the period of 1996–2017, Wang et al. (2020a) found that economic growth increases CO_2 emissions, but agriculture value added decreases CO_2 emissions in G7 countries. Balsalobre-lorente et al. (2019) employed DOLS and FMOLS techniques using data over the period 1990–2014 and confirmed the unfriendly impact of agriculture on the environment in Brazil, Russia, India, China, and South Africa. By using panel data from 1982 to 2015, Anwar et al. (2019) found that higher agricultural value added has an inverse association with CO_2 emissions in low- and lower-middle-income nations. Rafiq et al. (2016) found that economic development increases CO_2 emissions, but agricultural value added has a key impact in decreasing emissions using the STIRPAT model and yearly data from 1980 to 2010 for a set of 53 nations. On the other hand, using the FMOLS and DOLS methods utilizing time series data for the period 1971 to 2013, Appiah et al. (2018) reported that crop production index and livestock production index increase CO_2 emissions in selected emerging countries. Furthermore, by using the ARDL approach spanning from 1961 to 2012, Asumadu-Sarkodie and Owusu (2016) reported that CO_2 emissions affect the percentage annual change of agricultural area, coarse grain production, cocoa bean production, fruit production, vegetable production, and the total livestock per hectare of the agricultural area in Ghana.

In Vietnam's case, Shahbaz et al. (2019) revealed the positive effects of economic growth, energy use, and agriculture valued added on CO_2 emissions utilizing the ARDL approach using the data over 1974–2016. In addition, Phong et al. (2018) found positive impacts of economic growth and energy use on CO_2 emissions by employing the ARDL technique for Vietnam using the data over 1985–2015. Using the ARDL estimator for Vietnam spanning 1976–2009, Tang and Tan (2015) found that economic growth and energy use increases CO_2 emissions. By employing an ARDL estimator using yearly data between 1977 and 2019, Nguyen et al. (2021) reported that economic growth and energy use trigger CO_2 emissions in Vietnam. Al-Mulali et al. (2015) found the positive impacts of economic growth on CO_2 emissions in Vietnam by utilizing the yearly data spanning from 1981 to 2011 employing the ARDL approach. By using the FMOLS and DOLS methods, Khan et al. (2019) revealed a positive association between economic growth and CO_2 emissions in Vietnam. However, most environmental studies have concentrated on GHG emissions into the atmosphere through economic activities and energy consumption, leaving agricultural value added as a key determinant of environmental quality, especially in Vietnam. Therefore, this study attempts to explore the dynamic impacts of economic growth, energy use, and agricultural value added on CO_2 emissions in Vietnam.

3 Methodology

3.1 Data

This study used time series data from 1984 to 2020 for Vietnam and the data were obtained from the World Development Indicator (WDI) dataset. This research considered CO_2 emissions as the dependent variable while economic growth, energy use, and agricultural value added as explanatory variables. This study measured CO_2 emissions as kilotons, economic growth as GDP (constant Vietnamese Dong), energy use as kg of oil equivalent per capita, and agricultural value added as the percentage of GDP. Lastly, the variables were transformed into a logarithm to make sure that data were normally distributed. The variables with their logarithmic forms, measurement units, and data sources are presented in Table 1. Moreover, the annual trends of the study variables in Vietnam are presented in Fig. 1. It demonstrates that CO_2 emissions, GDP, energy use, and agricultural value added are constantly increasing.

3.2 Empirical model

Theoretically, CO_2 emission is associated with income and energy use. Assuming the market clearing condition, where CO_2 emissions equal economic growth and energy use, the following function is written within the framework of the standard Marshallian demand function (Friedman 1949) at time *t*:

$$CO_{2t} = f\left(GDP_t; EUt\right) \tag{1}$$

where CO_{2t} is the CO_2 emissions at time *t*, GDP_t is the economic growth at time *t*, and EU_t is the energy use at time *t*.

This study intended to estimate the impact of agricultural value added on CO_2 emissions in Vietnam. Hence, Eq. (1) can be as follows:

$$CO_{2t} = f\left(GDP_t; EU_t; AVA_t\right) \tag{2}$$

where AVA_t is the agricultural value added at time *t*.

The following equation depicts the economic model:

$$CO_{2t} = \tau_0 + \tau_1 GDP_t + \tau_2 EU_t + \tau_3 AVA_t \tag{3}$$

Further Eq. (3) can be expended as the econometric model in the following form:

Table 1 Variables with their logarithmic forms, units, and data sources

Variables	Description	Logarithmic forms	Units	Sources
CO_2	CO_2 emissions	LCO2	Kilotons	WDI
GDP	Economic growth	LGDP	Constant Vietnamese Dong	WDI
EU	Energy use	LEU	Kg of oil equivalent per capita	WDI
AVA	Agricultural value added	LAVA	Percentage of GDP	WDI

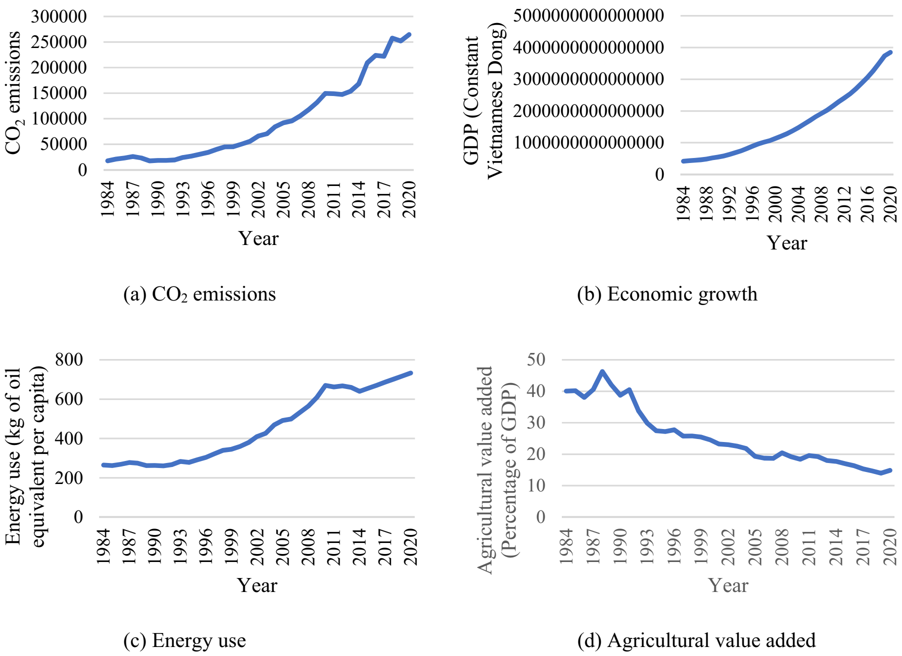

Fig. 1 Annual trends of the study variables in Vietnam. Source: World Bank (2022)

$$CO_{2t} = \tau_0 + \tau_1 GDP_t + \tau_2 EU_t + \tau_3 AVA_t + \varepsilon_t \quad (4)$$

where τ_0 and ε_t stand for intercept and error term, respectively. In addition, τ_1, τ_2, and τ_3 denote the coefficients.

Furthermore, Eq. (4) can be arranged logarithmically as follows:

$$LOC2_t = \tau_0 + \tau_1 LGDP_t + \tau_2 LEU_t + \tau_3 LAVA_t + \varepsilon_t \quad (5)$$

where $LCO2_t$ is the logarithmic form of CO_2 emissions at time t, $LGDP_t$ is the logarithmic form of economic growth at time t, LEU_t is the logarithmic form of energy use at time t, $LAVA_t$ is the logarithmic form of agricultural value added at time t.

3.3 Stationarity techniques for data

Avoiding spurious regression necessitates the use of a unit root test. It checks that variables in regression are stationary by differencing them and using stationary processes to estimate the equation of interest (Raihan and Tuspekova 2022b). The empirical literature acknowledges the need to define the sequence of integration before looking into cointegration among variables. According to some studies, it is critical to use more than one unit root test to evaluate the integration order of the series since unit root tests have different potency depending on the sample size (Raihan and Tuspekova 2022c, 2022d). To detect the autoregressive unit root, the present study used the Augmented Dickey-Fuller (ADF) test proposed by Dickey and Fuller (1979), the Dickey-Fuller generalized least squares (DF-GLS) test proposed by Elliott et al. (1992), and the Phillips-Perron (P-P) test proposed by Phillips and Perron (1988). The unit root test was used in this study to ensure that no variable exceeded the order of integration and to support the use of the DOLS technique over traditional cointegration methods.

3.4 Cointegration tests

This study applied the ARDL bounds test proposed by Pesaran et al. (2001) to capture the cointegration among the series. The ARDL bounds test for cointegration valuation has many advantages over the other one-time integer methods. Firstly, it can be utilized when series have a mixed order of integration as the ARDL bounds test does not have obligatory assumptions, and all variables must be incorporated in the same order in the analysis. Secondly, it is significantly more reliable, particularly for a small sample size. Thirdly, it offers an accurate estimation of the long-term model. Therefore, the ARDL bounds testing approach can be used irrespective of whether the fundamental returning system is in sequence apart in the I(2), and the cointegration order happens at I(0) or I(1). The ARDL bounds test is depicted as follows in Eq. (6):

$$\begin{aligned}\Delta \mathrm{LCO2}_t = \tau_0 + \tau_1 \mathrm{LCO2}_{t-1} + \tau_2 \mathrm{LGDP}_{t-1} + \tau_3 \mathrm{LEU}_{t-1} + \tau_4 \mathrm{LAVA}_{t-1} \\ + \sum_{i=1}^{q} \gamma_1 \Delta \mathrm{LCO2}_{t-i} + \sum_{i=1}^{q} \gamma_2 \Delta \mathrm{LGDP}_{t-i} + \sum_{i=1}^{q} \gamma_3 \Delta \mathrm{LEU}_{t-i} \\ + \sum_{i=1}^{q} \gamma_4 \Delta \mathrm{LAVA}_{t-i} + \varepsilon_t\end{aligned} \tag{6}$$

where Δ is the first difference operator and q is the optimum lag length in the above Eq. (6).

The ARDL bounds test follows the *F*-distribution, and its critical values were proposed by Pesaran and Timmermann (2005). The estimation procedure begins with Eq. (6) and uses OLS to enable the *F*-test to determine the joint significance of the coefficient of the lagged variables. The essence of this procedure is to examine the likelihood of any possible long-run relationship among the respective variables. In this regard, the null hypothesis (H_0) explains that cointegrating relationships do not exist among the regressors. The *F*-statistics can be compared against the critical values of the upper and lower bounds, as in Pesaran et al. (2001). If the *F*-statistics are higher than the upper critical value, the null hypothesis is rejected, which means the existence of a long-run relationship among the respective variables. On the other hand, if the *F*-statistics are less than the lower critical value, the null hypothesis is accepted. Alternatively, if the *F*-statistics are observed within the lower and upper critical values, the test is inconclusive.

Moreover, this study utilized the Johansen cointegration test (Johansen and Juselius 1990) and the Engle-Granger cointegration test (Engle and Granger 1987) as a robustness check to verify the ARDL bounds test findings. Johansen's test assesses the validity of a cointegrating relationship, using a maximum likelihood estimates (MLE) approach. Johansen cointegration test is used to find the number of relationships and estimate those relationships. It avoids the issue of choosing a dependent variable as well as issues created when errors are carried from one step to the next. The test can detect multiple cointegrating vectors and treats every test variable as an endogenous variable. There are two types of Johansen cointegration tests classified as the trace approach and the maximum eigenvalue approach. Both forms of the test determine if cointegration is present. Although the null hypothesis for both forms of the test is that there are no cointegrating equations, the difference is in the alternate hypothesis. The trace test alternate hypothesis is simply that the number of cointegrating relationships is at least one (shown by the number of linear combinations). In addition, the maximum eigenvalue test has an alternate hypothesis of K_0+1 (instead of $K>K_0$). Rejecting the null hypothesis in this situation is stating there is only one combination of the non-stationary variables that gives a stationary process. Furthermore, the Engle-Granger cointegration test considers the case that there is a single cointegrating vector. The Engle-Granger two-step method starts by creating residuals based on the static regression and then testing the residuals for the presence of unit roots. The Engle-Granger test follows the very simple intuition that if variables are cointegrated, then the residual of the cointegrating regression should be stationary. The Engle-Granger uses the Augmented Dickey-Fuller test to check if unit roots are present in the residuals. However, this study utilized both Johansen's test and the Engle-Granger test as Gonzalo and Lee (1998) recommended using both tests to discover or avoid any pitfalls.

3.5 ARDL technique via long- and short-run through VECM

This investigation employed the ARDL technique developed by Pesaran et al. (2001) to rectify the interaction amid variables through long- and short-run investigation. After confirming cointegration among the parameters, the study proceeded with the ARDL estimation of the long-run coefficient by using Eq. (6). After the long-term relationships have been identified, this study estimated the error correction model (ECM) developed by Engle and Granger (1987) to explore the short-run dynamics of the respective variables along with the short-run adjustment rate toward the long-run rate. This is achieved by adding the ECM to the ARDL framework demonstrated in Eq. (7):

$$\begin{aligned}\Delta \mathrm{LCO2}_t = \tau_0 + \tau_1 \mathrm{LCO2}_{t-1} + \tau_2 \mathrm{LGDP}_{t-1} + \tau_3 \mathrm{LEU}_{t-1} + \tau_4 \mathrm{LAVA}_{t-1} \\ + \sum_{i=1}^{q} \gamma_1 \Delta \mathrm{LCO2}_{t-i} + \sum_{i=1}^{q} \gamma_2 \Delta \mathrm{LGDP}_{t-i} + \sum_{i=1}^{q} \gamma_3 \Delta \mathrm{LEU}_{t-i} \\ + \sum_{i=1}^{q} \gamma_4 \Delta \mathrm{LAVA}_{t-i} + \theta \mathrm{ECM}_{t-1} + \varepsilon_t\end{aligned} \tag{7}$$

Where the speed of adjustment is depicted by θ, the first lag of the error term is illustrated by ECM_{t-1}, which signifies the error correction model.

This study also examined the stability tests of the coefficients by employing the cumulative sum of recursive residuals (CUSUM) and the cumulative sum of squares of recursive residuals (CUSUMSQ). In addition, this investigation performed normality, serial correlation, and heteroscedasticity analysis to validate the intensity of the cointegration valuation.

3.6 Cointegration regression to check the robustness of ARDL estimation

Although numerous econometric approaches can be employed to ascertain the long-run interconnection among the variables, this study employed the dynamic OLS (DOLS) approach proposed by Stock and Watson (1993), the fully modified OLS (FMOLS) introduced by Hansen and Phillips (1990), and Park's (1992) Canonical Cointegrating Regression (CCR) to check the robustness of ARDL outcomes. These approaches permit asymptotic coherence to be gathered by considering the impact of serial correlation (Raihan and Tuspekova 2022e, 2022f). The DOLS, FMOLS, and CCR can only be performed when there is evidence of cointegration among the series. Therefore, long-term elasticity is evaluated by utilizing DOLS, FMOLS, and CCR estimators using Eq. (6).

3.7 Toda-Yamamoto causality test

The present research intends to capture the causal relationship between the variables. Traditionally Granger causality test (Granger 1969) is employed to test for the causal relationship between variables. This test states that, if past values of a variable '*y*' significantly contribute to forecasting the future value of another variable '*x*' then '*y*' is said to Granger cause '*x*'. Time series must be stationary and integrated at the same level which is the most important condition to apply Granger causality. To avoid this problem Todo and Yamamoto (1995) suggested a newly developed method based on the Granger equation but augmented with extra lags. Toda and Yamamoto's (1995) causality analysis applies a standard VAR model while variables are in levels rather than first differences (unlike the Granger causality test) implying that the risk of wrongly identifying the order of integration of the series Moreover, Toda-Yamamoto causality could be used regardless whether a series is I(0), I(1) or even I(2). Therefore, this study utilized the Toda-Yamamoto causality analysis to examine the causal association between the variables. Three steps are involved with implementing the procedure which is to determine the maximal order of integration in the process d_{max}; to determine the optimal lag length k using Akaike Information Criterion (AIC), Schwarz Information Criterion (SC), Final Prediction Error (FPE) and Hannan–Quinn (HQ); and to estimate VAR($k + d_{max}$) model which is a developed approach for Wald test. The modified Wald test follows Chi-square (χ^2) distribution asymptotically and the degrees of freedom are equal to the number of time lags ($k + d_{max}$). One of the preconditions to apply the Toda-Yamamoto causality is that the order of integration of the process d_{max} does not exceed the true lag length k of the model. To clarify the principle, this research considers the simple example of a bivariate model (h_t, m_t), and conducts Toda-Yamamoto causality by estimating VAR ($k+d_{max}$) model as follows:

$$h_t = \alpha_0 + \sum_{i=1}^{k} \alpha_{1i} h_{t-i} + \sum_{k+1}^{k+d} \alpha_{2j} h_{t-j} + \sum_{i=1}^{k} \alpha_{1i} m_{t-i} \tag{8}$$

$$m_t = \beta_0 + \sum_{i=1}^{k} \beta_{1i} m_{t-i} + \sum_{k+1}^{k+d} \beta_{2j} m_{t-j} + \sum_{i=1}^{k} \beta_{1i} h_{t-i} \tag{9}$$

4 Empirical findings

4.1 Summary statistics

The outcomes of the summary measures amid variables are shown in Table 2 with the statistical values of different normality tests (skewness, probability, kurtosis, and Jarque–Bera) and correlation between the variables. Each variable includes 37 observations of time series data from 1984 to 2020 for Vietnam. The skewness values close to zero imply that all the variables adhere to normality. Furthermore, the research employed kurtosis to evaluate if the series is light-tailed or heavy-tailed relative to normal distribution. The empirical findings indicate that all the series are platykurtic as their values are less than 3. In addition, the smaller

Table 2 Descriptive and correlation statistics

Variables	LCO2	LGDP	LEU	LAVA
Mean	11.08323	34.77347	6.082869	3.181020
Median	11.10164	34.78952	6.016524	3.136773
Maximum	12.74323	35.88612	6.881631	3.835078
Minimum	9.770523	33.66690	5.563719	2.635944
Std. Dev	0.947610	0.701506	0.448173	0.347179
Skewness	0.097364	− 0.062654	0.312547	0.351850
Kurtosis	1.658827	1.737688	1.632504	1.959303
Jarque–Bera	2.831524	2.480748	3.485381	2.433124
Probability	0.242741	0.289276	0.175049	0.296247
Sum	410.0796	1286.619	225.0662	117.6978
Sum Sq. Dev	32.32671	17.71600	7.230917	4.339208
Observations	37	37	37	37
Correlation between the variables				
	LCO2	LGDP	LEU	LAVA
LCO2	1.000000	0.985454	0.991811	-0.959062
LGDP	0.985454	1.000000	0.976397	− 0.978174
LEU	0.991811	0.976397	1.000000	− 0.935043
LAVA	− 0.959062	− 0.978174	− 0.935043	1.000000

values of the Jarque–Bera probability reveal that all the parameters are normal. Furthermore, the results of correlation analysis revealed that all the variables are correlated to one another. LCO2, LGDP, and LEU indicate a very strong and positive correlation with each other which implies that when the value of one variable rises, the value of the other tends to rise as well and vice versa. Nevertheless, LAVA shows a strong but negative correlation with all the other variables, which reveals that when the value of agricultural value added rises, the other variable's value tends to drop, and vice versa.

4.2 Results of unit root tests

Table 3 presents the findings of unit root testing using ADF, DF-GLS, and P-P tests. The results revealed that LCO2, LEU, and LAVA were non-stationary at the level but became stationary at the first difference in all three unit root tests. In addition, LGDP was stationary at the level and stayed stationary after taking the first difference in the ADF test, while LGDP was found non-stationary at the level but became stationary at the first difference in DF-GLS and P-P tests. The results of the unit root test show that the series is stationary at mixed levels of either level or first-order integration, I(0) or I(1), which is suitable for using the ARDL approach. Furthermore, the presence of mixed orders integration for variables estimated by the ADF, DF-GLS, and P-P tests supports the employment of the Johansen and Engle-Granger cointegration tests to capture cointegration among the series.

4.3 Results of the cointegration tests

4.3.1 Cointegration with bounds testing

After the stationarity characteristics of the series are affirmed, this study proceeded to estimate the ARDL framework. To conduct the ARDL bounds test for cointegration valuation, this analysis chose a reasonable lag period to measure the *F*-statistic constructed on the minimum values of the Akaike Information Criterion (AIC). Table 4 presents the ARDL bounds test results to explore

Table 3 The results of unit root tests

Logarithmic form of the variables		LCO2	LGDP	LEU	LAVA
ADF	Log levels	0.727771	– 2.811133**	2.054307	– 0.641829
	Log first difference	– 4.285315***	– 2.458702**	– 4.628685***	– 5.398078***
DF-GLS	Log levels	0.959485	– 1.241523	0.422350	0.349964
	Log first difference	– 3.807161***	– 1.950715*	– 3.931232***	– 5.108933***
P-P	Log levels	– 0.727771	– 0.023099	2.054307	– 0.641829
	Log first difference	– 4.314584***	– 2.458702**	– 4.628685***	– 5.360733***

***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively

Table 4 The results of the ARDL bounds test

F-bounds test		Null hypothesis: No levels of relationship		
Test statistic	Value	Significance (%)	I(0)	I(1)
Value of *F*-statistic	8.388212	At 10	2.37	3.20
K	3	At 5	2.79	3.67
		At 2.5	3.15	4.08
		At 1	3.65	4.66

the cointegration link among the variables. The outcomes are presented in such a manner that the existence of a long-run association between the parameters is verified if the estimated value of the *F*-test is greater than the values of both limits (lower and upper bound). The findings revealed that the estimated *F*-statistic value (8.388212) is higher than 10%, 5%, 2.5%, and 1% of the crucial upper limit in the order zero and one which rejects the null hypothesis by indicating that a long-run relationship exists among respective variables.

4.3.2 Johansen cointegration test

The results of the Johansen cointegration estimations are presented in Table 5 which displays the *t*-statistics and maximal Eigenvalues at 0.05 critical values (CV). The trace test examined the number of linear combinations in time series data whereas Eigenvalue is a non-zero vector that changes when a linear transformation is performed on it. The *t*-statistic values from the Trace test indicate that there is a

Table 5 The results of the Johansen cointegration test

Trace test outcomes				
H-no. of CE(s)	*E* values	*t* statistic	CV (0.05)	*p* values**
None*	0.580310	65.75794	47.85613	0.0005
At most 1*	0.567524	40.57902	29.79707	0.0020
At most 2*	0.376215	16.27039	15.49471	0.0382
At most 3	0.085245	2.583866	3.841465	0.1080
M-Eigenvalue outcomes				
H-no. of CE(s)	*E* values	*M* Eigen Statistic	CV (0.05)	*p* values**
None	0.580310	25.17892	27.58434	0.0985
At most 1*	0.567524	24.30863	21.13162	0.0172
At most 2	0.376215	13.68652	14.26460	0.0615
At most 3	0.085245	2.583866	3.841465	0.1080

*Rejection of the hypothesis at 0.05 level;

***p* values of MacKinnon et al. (1999)

cointegrating vector among the variables at the 5% significance level. The Maximum Eigen statistics also show cointegrating equations at the 5% level verifying the Trace Test. As a result, these two tests demonstrated the existence of a long-run cointegrating association between CO_2 emissions, economic growth, energy use, and agricultural value added in Vietnam. This result corroborates the findings of the ARDL bounds test. The Johansen cointegration test provides estimates of all cointegrating vectors which suggests proceeding with the ARDL long-run and Vector Error Correction Model (VECM).

4.3.3 Engle-Granger cointegration test

The results of the Engle-Granger cointegration test are displayed in Table 6. The null hypothesis of no cointegration is rejected by the negative coefficient of both tau-statistic and *z*-statistic values. All of the variables appear to be cointegrated, according to the evidence. The d.f. corrected coefficient standard error and the squared standard error of the regression are the Rho S.E. and Residual variance, respectively. The long-run residual variance is based on the estimated parametric model and is an estimate of the residual's long-run variance. By dividing the residual variance by the square of 1 minus the sum of the lag difference coefficients, the estimator is obtained. The denominator of the *z*-statistic is calculated using the residual variance and long-run variances. Finally, the number of stochastic trends is the number of cointegrating variables (including the dependent) in the model. As the Engle-Granger test shows the presence of cointegration and validates the results from the Johansen cointegration test, the analysis led us to continue the estimate of long-run and short-run coefficients by using the ARDL approach.

Table 6 The results of the Engle-Granger cointegration test

Dependent	Tau-statistic	*p* values*	*z* statistic	*p* values*
LCO2	− 2.962579	0.4716	− 14.55810	0.4140
LGDP	− 3.699772	0.1897	− 29.12661	0.0079
LEU	− 2.994565	0.4567	− 12.52780	0.5534
LAVA	− 3.541162	0.2360	− 18.18685	0.2126
	Intermediate results of the Engle-Granger cointegration test			
	LCO2	LGDP	LEU	LAVA
Rho–1	− 0.485270	− 0.659592	− 0.417593	− 0.606228
Rho S.E	0.163800	0.178279	0.139450	0.171195
Residual variance	0.002387	0.000837	0.000946	0.002085
Long-run residual variance	0.002387	0.001941	0.000946	0.002085
Lags number	0	1	0	0
N-observations	30	29	30	30
N-stochastic trends**	4	4	4	4

**p* values of MacKinnon (1996)

**stochastic trends number in the asymptotic distribution

4.4 ARDL long-run and short-run results

After confirming cointegration among the variables, the long-run impacts of economic growth, energy use, and agricultural value added on CO_2 emissions in Vietnam are explored by utilizing the ARDL long- and short-run estimation. Table 7 presents the estimated long-run coefficients using the ARDL model. The estimated long-run coefficient of LGDP is positive and significant at the 5% level, which implies that a 1% increase in economic growth will lead to a 0.89% increase in CO_2 emissions when other indicators are held constant. This finding revealed that economic growth triggers environmental degradation in the long run. Moreover, the estimated long-run coefficient of LEU is positive and significant at the 1% level, which reveals that an increasing 1% in energy use is linked with a rising 1.75% of CO_2 emissions in Vietnam. This implies that in the long run, energy consumption deteriorates environmental quality. Furthermore, the estimated coefficient of agricultural value added is negative and significant at a 1% level, implying that an increase in agricultural value added by 1% is associated with CO_2 emissions reduction by 0.72% in the long run. This discloses that agricultural value added improves the environmental quality in Vietnam as the cropland absorbs the atmospheric CO_2 and stores it as biomass carbon.

The stability of the long-run coefficient was verified by the short-run dynamics. This model obtains the short-run dynamic parameters by estimating an error correction model (ECM) associated with the long-run estimates. The ECM is important in time series analysis as it allows for a better understanding of long-run dynamics by using adjustment coefficients to measure the forces that push the relationship toward long-run equilibrium. The ECM reflects the long-run equilibrium relationships of variables that describe how variables adjust when they are out of equilibrium. The results of the short-run dynamic coefficients associated with the long-run relationship are presented in Table 8. The estimated short-run coefficient of LGDP is positive and significant at the 5% level which is harmonized with the long-run result. The outcome from the short-run estimation indicates that keeping other indicators constant, a 1% increase in economic growth causes CO_2 emissions to rise by 1.11%. The coefficient of LEU is positive and significant at the 1% level in the short run, which implies that a 1% increase in energy consumption is associated with a 1.68% increase in CO_2 emissions in the short run. Furthermore, the coefficient of LAVA is negative and significant at the 1% level which reveals that a 1% increase in agricultural value added is linked

Table 7 Estimated long-run coefficients using the ARDL approach: dependent variable LCO2

Variables	Coefficient	Standard Error	*t* statistics	*p* value
LGDP	0.893988**	0.190427	4.694647	0.0199
LEU	1.753483***	0.284316	6.167382	0.0000
LAVA	− 0.723517***	0.164424	− 4.400314	0.0002
C	10.41673	4.209266	2.474714	0.2289

***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively

Table 8 Error correction representation of the ARDL model: dependent variable LCO2

Regressor	Coefficient	Standard Error	*t*-statistics	*p*-value
ΔLGDP	1.113652**	0.344817	3.229689	0.0329
ΔLEU	1.681861***	0.197673	8.508299	0.0000
ΔLAVA	− 0.523387***	0.169321	− 3.091090	0.0046
ΔC	19.59699	8.714871	2.248684	0.1066
ECM (−1)	− 0.531547***	0.076599	− 6.939348	0.0000

ECM = LCO2 − (1.1136×LGDP + 1.6818×LEU − 0.5233×LAVA + 19.5970)

***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively

with a reduction of CO_2 emissions by 0.52% in the short run. In addition, the coefficient of the ECM is 0.5315, which is significant at the 1% significance level and implies that disequilibrium in the short-run was adjusted by 53% per year towards the long-run equilibrium. The short-run dynamic coefficients from the error correction model indicate that economic growth and energy use hamper the quality of the environment while enhancing agricultural value added improves the environmental quality in Vietnam.

4.5 Diagnostic inspection

The ARDL-VECM model diagnostic tests are presented in Table 9. The R^2 and adjusted R^2 values are 0.9960 and 0.9955, respectively, indicating that the calculated regression model fits very well. This means that the independent factors can account for 99% of the variation in the dependent variable's change. The ARDL test

Table 9 The results of ARDL model diagnostic tests

Diagnostic tests	Coefficient	*p*-value	Decision
R^2	0.998113		The model is well fitted
Adjusted R^2	0.997624		The model is well fitted
Functional Form	1.362562	0.0034	No functional error
Jarque–Bera test	0.098971	0.9512	Residuals are normally distributed
Lagrange Multiplier test	0.675232	0.5181	No serial correlation exits
Breusch-Pagan-Godfrey test	1.382065	0.2530	No heteroscedasticity exists
Harvey test	0.947445	0.4877	No heteroscedasticity exists
Glejser test	1.054318	0.4184	No heteroscedasticity exists
F-statistic	2040.672	0.0000	The model's linear relationship is statistically significant
Root mean square error (RMSE)	0.042566		The model is well fitted
Mean absolute error (MAE)	0.037124		The model is well fitted
Bias proportion	0.000148		The model is not biased
Ramsey RESET test	2.981952	0.1265	The regression is properly specified

also passed several diagnostic tests, with no serial correlations, functional errors, or heteroscedasticity problems of the models estimated in this study. The ARDL-VECM model diagnostic tests indicate that the model is well-fitted. Moreover, the *F*- statistic indicates that the dependent and independent variables support the estimated ARDL regression. The *F*- statistic has a p-value of 0.0000, indicating that the model's linear relationship is statistically significant. In addition, the root mean square error (RMSE) and the mean absolute error (MAE) provide an accurate estimate of model predictions. The RMSE and MAE values are 0.04 and 0.03 respectively, which are near 0 and non-negative, indicating that the model's results were a near-perfect fit to the data. The Ramsey RESET test revealed an insignificant value of the coefficients, indicating that the regression is properly specified. Furthermore, the present study employed the cumulative sum of recursive residuals (CUSUM) and cumulative sum of squares of recursive residuals (CUSUMQ) tests to check the stability of the model. The CUSUM and CUSUMQ plots at a 5% significance level are presented in Fig. 2. The values of the residuals are represented by blue lines, while the confidence levels are represented by red lines. At a 5% significance level, the calculated results show that the studied residuals' values remain within the lines of confidence, which confirms the model's stability.

4.6 Robustness check

The current study utilized the DOLS, FMOLS, and CCR estimators to verify the consistency of ARDL long-run estimation. The outcomes of DOLS, FMOLS, and CCR provide evidence of the robustness of the ARDL estimation by the present study.

4.6.1 Dynamic OLS (DOLS)

The results of the DOLS estimation are presented in Table 10 which indicates that the outcomes are harmonized with the ARDL estimation. The coefficients of economic growth and energy use are positive and significant, which complies with the long-run and short-run coefficients of the ARDL model. In addition, the

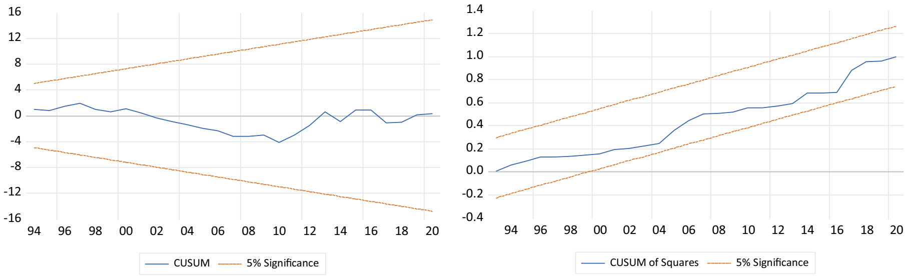

Fig. 2 Plot of CUSUM and CUSUMQ tests (critical bounds at 5% significance level)

Table 10 The outcomes of DOLS: dependent variable LCO2

Variables	Coefficient	Standard error	*t* Statistic	*p* value
LGDP	0.965443**	0.270946	3.563230	0.0186
LEU	1.548507***	0.248558	6.229965	0.0000
LAVA	− 0.619251**	0.333522	− 1.856703	0.0237
C	1.358034	9.158877	0.148275	0.8830
R^2	0.991702			
Adjusted R^2	0.990947			

***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively

negative and statistically significant coefficient of LAVA indicates that CO_2 emissions decrease with the increase in agricultural value added.

4.6.2 Fully modified OLS (FMOLS)

The long-run results of the FMOLS estimation for the model are presented in Table 11. The FMOLS estimation results verified the positive and significant relationship of CO_2 emissions with economic growth and energy use in Vietnam. In addition, the FMOLS results confirmed the significant inverse relationship between CO_2 emissions and agricultural value added. The results of the FMOLS are duly in line with the findings from the ARDL model's long-run and short-run results.

4.6.3 Canonical cointegrating regression (CCR)

The outcomes of the CCR estimation are presented in Table 12. The CCR estimation results show that economic growth and energy consumption damage the quality of the environment in Vietnam. Furthermore, the empirical findings from CCR revealed that increased agricultural value added improves the quality of the environment. Table 12 shows that the coefficients of the study variables found from the CCR estimator are significant and identical to the outcomes from FMOLS and DOLS estimators as well as the ARDL long-run and short-run estimation.

Table 11 The results of FMOLS: dependent variable LCO2

Variables	Coefficient	Standard error	*t*-Statistic	*p*-value
LGDP	0.935465**	0.202726	4.614431	0.0194
LEU	1.517872***	0.186074	8.157345	0.0000
LAVA	− 0.772932***	0.235348	− 3.284203	0.0025
C	5.101333	6.776557	0.752791	0.4571
R^2	0.991465			
Adjusted R^2	0.990664			

***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively

Table 12 The results of CCR: dependent variable LCO2

Variables	Coefficient	Standard error	*t*-Statistic	*p*-value
LGDP	0.926743**	0.195482	4.740809	0.0196
LEU	1.480282***	0.176546	8.384702	0.0000
LAVA	− 0.726674***	0.236882	− 3.067663	0.0044
C	3.584497	6.592366	0.543735	0.5904
R^2	0.991329			
Adjusted R^2	0.990516			

***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively

4.7 Results of the Toda-Yamamoto causality test

Table 13 presents the results of the Toda-Yamamoto causality analysis. The test results indicate causality running from LGDP to LCO2, LEU to LCO2, LAVA to LCO2, LAVA to LGDP, LGDP to LEU, and LAVA to LEU due to statistical significance leading to the rejection of the null hypothesis. This indicates that economic growth causes CO_2 emissions, energy use causes CO_2 emissions, agricultural value added causes CO_2 emissions, agricultural value added causes economic growth, economic growth causes energy use, and agricultural value added causes energy use in Vietnam.

5 Discussion

The present study investigated the relationship between economic growth and environmental pollution in the case of Vietnam. The examined result of economic growth shows a positive and significant effect on CO_2 emissions in the long run. According to the findings, in Vietnam, increased economic expansion is linked to a decrease in environmental sustainability. The result of this study is supported by Al-Mulali et al. (2015), Tang and Tan (2015); Phong et al. (2018), Khan et al. (2019), Shahbaz et al. (2019), and Nguyen et al. (2021) who found a positive connection between GDP and CO_2 emissions in Vietnam. Moreover, several studies have been carried out to determine the link between CO_2 emissions and economic growth for

Table 13 The results of the Toda-Yamamoto causality test

	Dependent variable			
Causality variable	LCO2	LGDP	LEU	LAVA
LCO2	–	0.3244	1.7866	0.5128
LGDP	18.3541***	–	13.4699***	1.7378
LEU	20.5364***	1.7925	–	1.2585
LAVA	13.4151***	17.5678**	8.7008**	–

***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively

various countries which are allied with the result of the present study. For example, Begum et al. (2015), Sehrawat et al. (2015), Raihan (2023b), Dogan (2016), Jebli and Youssef (2017), Liu et al. (2017), Raheem and Ogebe (2017), Akbota and Baek (2018), Liu and Bae (2018), Ahmed et al. (2019), Vo et al. (2019), Adebayo (2020), Adebayo et al. (2020), Begum et al. (2020), Kirikkaleli and Kalmaz (2020), Odugbesan and Adebayo (2020), Nondo and Kahsai (2020), Prastiyo et al. (2020), Wang et al. (2020a), Wang et al. (2020b), Zmami and Ben-Salha (2020), Raihan and Voumik (2022a), Adebayo and Kalmaz (2021), Raihan et al. (2022e), Islam et al. (2021), Raihan and Voumik (2022b), Teng et al. (2021), Raihan and Tuspekova (2022g), and Raihan et al. (2022f). Furthermore, the present study found a unidirectional causal relationship running from economic growth to CO_2 emissions in Vietnam which is aligned with Tang and Tan (2015), and Nguyen et al. (2021). In addition, the present study revealed a unidirectional causal relationship running from economic growth to energy use which is supported by Tang and Tan (2015).

However, rising economic growth is associated with greater environmental pollution. It adds to more societal demands being satisfied through consumption and development activities, resulting in more pollution, waste, and environmental deterioration (Raihan et al. 2022g). Thus, economic activities appear acceptable for environmental protection and development rather than constituting a danger to long-term environmental quality (Raihan and Tuspekova 2022h). Since 2014, Vietnam has modified its national law on environmental protection to reflect the worldwide goal for comprehensive and sustainable growth. Cap and trade, for example, focuses on creating a domestic carbon credit market in which corporations are limited in their emissions and can exchange the surplus with other companies to reduce the cost of emissions if they do not reach the cap. Companies, on the other hand, are required to report their emissions to the relevant authority regularly to ensure that the quota is adhered to (Nguyen et al. 2021). Vietnam aspires to progress towards sustainable resource consumption by implementing low-carbon policies to reduce the demand for and usage of energy by various industrial sectors.

This study examined the interconnection between energy use and environmental pollution in Vietnam. The findings of the energy usage analysis led to a favorable and major influence on CO_2 emissions in the long run. The finding shows that increasing energy consumption degrades Vietnam's environmental quality. The study's findings are consistent with the other studies on Vietnam by Tang and Tan (2015), Phong et al. (2018), Shahbaz et al. (2019), and Nguyen et al. (2021). Furthermore, the result of the positive relationship between energy use and CO_2 emissions is allied with the previous studies that pointed out that various countries rely heavily on energy sources such as coal, natural gas, and oil leading to increased CO_2 emissions and hence environmental degradation. For example, Begum et al. (2015), Sehrawat et al. (2015), Raheem and Ogebe (2017), Akbota and Baek (2018), Liu and Bae (2018), Ahmed et al. (2019), Vo et al. (2019), Adebayo (2020), Adebayo et al. (2020), Kirikkaleli and Kalmaz (2020), Odugbesan and Adebayo (2020), Nondo and Kahsai (2020), Wang et al. (2020b), Zmami and Ben-Salha (2020), Adebayo and Kalmaz (2021), Teng et al. (2021), Raihan and Tuspekova (2022i), and Islam et al. (2021). Moreover, the Toda-Yamamoto causality test reveals a unidirectional causal relationship in Vietnam between energy consumption and CO_2 emissions, which is corroborated by Tang and Tan (2015), and Nguyen et al (2021).

This study confirmed that Vietnam's principal energy source is fossil fuels, which are directly responsible for environmental damage. Vietnam is an oil and coal-producing country, thus the national energy plan that promotes fossil-fuel-based economic development is understandable. As a result, industrial and residential activities have a significant negative impact on the environment. Another concern is that fossil fuels are non-renewable energy sources, which means that overexploitation will result in their depletion, and economic development scenarios reliant on fossil fuels would fail. As a result, Vietnam's officials have set a target of developing a roadmap to lower the share of coal-fired power and cut GHG emissions from energy activities by 15% by 2030. To achieve these goals, legislators created and developed the carbon credit market to reduce emissions from economic activity (Nguyen et al. 2021). Vietnam has made significant efforts toward a low carbon energy structure through the application of policy and technology to assist keep global temperature rise well below 2 °C compared to pre-industrial levels by the end of this century.

However, coal-fired power plants generate half of Vietnam's total electricity, raising worries about GHG emissions and their effects on human health and the environment. As a result, the most important policy is to establish a mature renewable energy infrastructure that eventually replaces coal. Since the turn of the century, Vietnam has been developing renewable energy, while coal-based energy output has remained unchanged. With climate change looming, employing renewable energy sources for energy production is critical to ensuring sustainable development and mitigating climate change (Raihan et al. 2022h). Renewable energy delivers significant economic advantages in addition to decreasing carbon emissions, such as increased energy availability, improved energy security, and the use of local renewable resources (Raihan et al. 2022i; Voumik et al. 2022a). As a result of rising global environmental awareness, it is critical to shift Vietnam's energy balance to renewables to enable the use of sustainable energy sources and the development of an environmentally sustainable ecosystem (Raihan et al. 2023c). Solar, wind, hydro, and biomass all have significant renewable energy potential in the country. Despite this, a variety of technical, institutional, social, and economic constraints have prevented these resources from being harnessed and utilized sustainably. Thus, Vietnam requires a comprehensive strategy to promote renewable energy production to accomplish a low-carbon transition.

Moreover, this research uncovered a significantly negative link between agricultural value added and CO_2 emissions in Vietnam, suggesting that reducing agricultural value added increases CO_2 emissions in the long run. Instead, agricultural value added improves environmental quality as the forest and cropland absorb the atmospheric CO_2 and store it as biomass carbon. The scrutinized study result is aligned with the other studies on Vietnam, such as Shahbaz et al. (2019). The result of this study is consistent with several studies from different countries, such as Dogan (2016), Rafiq et al. (2016), Jebli and Youssef (2017), Liu et al. (2017), Balsalobre-lorente et al. (2019), Prastiyo et al. (2020), Anwar et al. (2019), Wang et al. (2020a), Raihan and Tuspekova (2022j), and Raihan (2023c). Furthermore, Shahbaz et al. (2019) confirm the current study's finding of a unidirectional causal association between agricultural value added and economic growth in Vietnam. Agriculture is an important source of employment for women in Southeast Asia (Voumik et al. 2022b). Agriculture value added has a significant causality to economic growth but not to carbon emissions. According to Raihan (2023a), agricultural value added first leads to an improvement in environmental quality up to a point where it harms the environment, making the agriculture sector a CO_2 emitter.

However, the percentage share of agriculture in Vietnam's GDP continues to fall over time (World Bank 2022) due to industrialization. The outcome of the present study suggests that traditional agricultural methods should be replaced by modern technologies, which would increase agricultural value added and reduce emissions while ensuring food security in Vietnam. The IPCC (2014) reported that achieving the goal of reducing GHGs emissions from the agriculture sector would not only result in a cleaner environment but will also provide new sources of income as more farming operations may be carried out. The agriculture industry might help to reduce GHGs emissions by using correct farming techniques. Carbon release may be stored by agricultural operations when proper management and technology are used, resulting in a reduction in carbon footprint (Raihan and Tuspekova 2022k). Various international organizations have recently developed a climate-smart agriculture (CSA) method to change agricultural growth to mitigate environmental damage. These projects have a long-term impact on global climate change reduction and mitigation.

Vietnam has become a world-leading exporter of several agricultural commodities. Agriculture has helped Vietnam achieve some millennium development goals. It is the driving force and the mitigating factor that has helped the country overcome several regional and global crises. The Vietnamese government is working hard to accomplish environmental sustainability, agricultural growth, improved farmer livelihoods, and rural development all at the same time. In terms of climate change, the government amended numerous key documents in 2020 that serve as the foundation for existing agricultural and rural development climate change policies. These include the agricultural sector's action plan to adapt to and mitigate climate change for the period 2021–2030, with a vision for 2050, and the agricultural sector's strategy to carry out the government's action plan to implement the Paris Agreement on Climate Change. Vietnam has promised to reduce GHG emissions by 8% by utilizing domestic resources between 2021 and 2030, compared to business-as-usual (BAU) levels. The government has set a lofty goal of lowering GHG emissions in agriculture and rural areas by 20% every ten years by implementing crop and animal husbandry methods, including climate-smart agriculture.

6 Conclusion and policy implications

6.1 Conclusion

The present study empirically investigated the dynamic impacts of economic growth, energy use, and agricultural value added on CO_2 emissions in Vietnam. To investigate the short-run and long-run relationship between the variables, this research employed the autoregressive distributed lag (ARDL) technique and demonstrated it through the Vector Error Correction Model (VECM) by using the time series data from 1984 to 2020 for Vietnam. The integration order of the series was captured using ADF, DF-GLS, and P-P unit root tests in this study. The ARDL bounds test revealed evidence of cointegration among the variables in the long run which are verified by the Johansen cointegration test and Engle-Granger cointegration test. The empirical findings from ARDL estimation indicate that economic growth and energy use trigger environmental degradation by increasing CO_2 emissions while enhancing agricultural value added improves Vietnam's environmental quality by reducing CO_2 emissions in both the long run and short run. The estimated results are robust to DOLS, FMOLS, and CCR estimators. In addition, the Toda-Yamamoto causality test was utilized to capture the causal linkage between the variables. This research contributes to the existing literature by shedding light on the potential of agricultural value added to reduce emissions in Vietnam. This article put forward policy recommendations aimed at sustainable development by establishing strong regulatory policy instruments to reduce environmental degradation.

6.2 Policy implications

The outcome of the present study suggests that the policymakers in Vietnam prepare an environmental policy that reduces CO_2 emissions without jeopardizing economic growth. In Vietnam, the greatest strategic choice for combating climate change is a low-carbon economy. To avoid pollution at the source, the "pollute first, then treat" strategy might be altered, and the economic development mode at the expense of the environment could be transformed. In this regard, the present study recommends the government assist markets by building a robust legislative framework that generates long-term value for emission reductions and continually promotes innovative technologies that lead to an economy that is less carbon-intensive. In addition, the Vietnam government can set up some regulations, such as a high carbon tax, carbon capture, carbon storage, and emission trading schemes to reduce CO_2 emissions from fossil fuel use in power generation and industry. To achieve the effect of decoupling at the regional level, significant changes are required in a centralized state policy, patterns of behavior, and the pace of scientific and technological progress. The exploitation of natural resources and manufacturing industries, rather than the development of science-intensive items, account for the majority of Vietnam's economy, and GDP growth. In this regard, the primary task is government support for research and development, aimed at increasing the resource intensity and energy efficiency of production and modernization based on innovations aimed at meeting growing needs, while minimizing the impoverishment of natural capital. Additionally, Vietnam might shift its focus from extensive to intensive growth and alter its economic development pattern by focusing not only on economic output but also on improving the green economy. In addition, fostering the economic transition to renewables is critical for reducing the environmental pressures caused by economic development. Renewable energy companies and technology could also be encouraged and promoted by policymakers. By displacing CO_2-intensive conventional energy sources, these measures would assist the economy in increasing the percentage of renewable energy consumption in overall energy consumption. In addition, institutional alignment is required to encourage renewable energy consumption across economic activities and assure long-term economic growth. Finally, rigorous adherence to environmental rules is required. These measures will ensure that the country's goal of rapid economic growth and transformation does not come at the expense of environmental quality.

Vietnam's long-term prosperity could be enhanced by developing and implementing effective regulations to control the country's industrial sector practices. To optimize the energy usage structure, the current study recommends that more clean energy or renewable energy be used. Vietnam's energy usage structure is still based on traditional high-carbon energy sources. Vietnam may move to renewable resources to replace traditional fossil fuels in order to minimize GHG emissions. Solar energy, hydroelectric, and wind power resources abound in Vietnam, allowing the country to meet its entire domestic energy needs. As a result, Vietnam may be able to create technical assistance networks with other countries while also proactively growing its renewable resources. The government could expand financial support for renewable energy promotion. In Vietnam, there is plenty of potential and actual renewable energy, but promotion is hampered by higher economic expenses. Vietnam might develop measures to lower the cost of renewable energy and discourage the use of fossil fuels in industries, companies, and households since renewable energy use can help to reduce emissions. Furthermore, Vietnam could continue to increase its energy use efficiency. Because the efficiency of energy consumption is largely determined by technical advancement, Vietnam might increase its investments in innovative energy-saving technology and stimulate research and development in this area. At the same time, it may encourage innovation in energy exploitation, transformation, and utilization. Furthermore, public education programs on energy conservation and utilization efficiency in Vietnam could be intensified. Since Vietnam is still a developing economy, if cleaner energy is more expensive, the public will prefer cheaper energy, even if it results in higher carbon emissions. Tax incentives, financial subsidies, and government procurements are all examples of fiscal measures that the government might use to encourage people to switch to cleaner energy. The government might use the media to promote its green lifestyle concept and campaign for low-carbon lifestyles and consumption habits. Vietnam may relieve energy stress while also lowering carbon emissions with these strategies. Moreover, because the ongoing COVID-19 epidemic has had an impact on energy consumption patterns, the government might carefully create policies. In Vietnam, for example, residential energy use has increased while transportation energy consumption has decreased. Hence, authorities would concentrate on promoting energy-efficient residential electric appliances as well as more affordable renewable energy sources for the household sector.

This study suggests the policymakers of Vietnam design effective policies to improve environmental quality by increasing agricultural value added. Increased efforts are needed to enhance agricultural value added by introducing modern agro-based technology including high-yield and disease-resistant crop varieties, as well as persuading farmers to reject old farming practices in favor of more advanced agrarian approaches. Moreover, agricultural value-added components may be improved at a greater level with the help of contemporary agricultural technology and the availability of good seeds and other agricultural inputs. Sustainable agriculture may minimize emissions and increase carbon sequestration by establishing organic and low-carbon agriculture systems. To accomplish long-term agricultural value added, the government might encourage more efficient energy infrastructure and support the switch to cleaner, more efficient energy sources in agriculture. The government could support the use of renewable energy, particularly clean renewable energy like solar and wind because it boosts agricultural value added while also helping to battle global warming and climate change. Subsidies for renewable energy use in agriculture would help the industry become more competitive in worldwide markets while emitting less pollution. For a carbon–neutral environment, irrigation methods can be switched from non-renewable to renewable energy sources. Other important agricultural changes include encouraging farming people to use solar tube wells for irrigation, organic farming, tunnel farming, changing traditional tillage to no-till, and reducing fertilizer use to decrease environmental impact. These contemporary agriculture technologies can help large farms cut personnel, improve productivity, and cut emissions. Excessive use of fertilizers and pesticides must be avoided, and green production must take precedence for the sake of sustainable agriculture and pollution reduction. The agriculture industry may have a significant positive impact on the environment by using an organic framework. Furthermore, boosting agricultural investment in Vietnam through improved international collaboration would aid in the reduction of emissions from Vietnam's agriculture sector while increasing agricultural value added.

6.3 Limitations and future research opportunities

Although the present study has produced substantial empirical outcomes in the case of Vietnam, the analysis has several limitations that might be addressed in future research. One of the critical drawbacks of our analysis is the unavailability of data regarding economic growth and agricultural value added beyond the period of study, which limits the power of the econometric techniques used. Nevertheless, this study explored the dynamic interaction of economic growth, energy use, and agricultural value added on CO_2 emissions in Vietnam utilizing current time series data. Further research might be undertaken for other developing countries while utilizing different econometric modeling or the usage of micro-disaggregated data. Moreover, future research can account for other growth determinants that have not been addressed in this study, such as trade openness, financial development, foreign direct investments, urbanization, industrialization, institutional quality, globalization, technological innovation, forested area, etc. However, this study utilized CO_2 as an indicator of environmental degradation. Further studies could be conducted by utilizing consumption-based carbon emissions as a proxy for environmental degradation, or other measures of environmental emissions such as nitrous oxide (N_2O) and sulfur dioxide (SO_2), methane (CH_4), carbon monoxide (CO), ground-level ozone (O_3), hydrogen sulfide (H_2S) and other short-lived climate forces (SLCF) to improve the overall environmental quality in Vietnam. Nevertheless, CO_2 emission is utilized as a representation of environmental degradation in the present study, which is not the only cause of environmental pollution. More environmental pollution indicators, such as water pollution and land pollution, could be included in future research for the case of Vietnam to investigate this interconnection. Furthermore, future research can compare country-specific results to overall panel outcomes utilizing advanced econometric approaches, in addition to panel estimations. These could provide useful comparisons with the findings of this study, shedding light on the relevant literature.

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Data availability All data generated or analyzed during this study are available here: https://databank.worldbank.org/source/world-development-indicators.

Declarations

Conflict of interest The author declares no conflict of interest.

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