Innovation and Green Development 4 (2025) 100229

Contents lists available at ScienceDirect

Innovation and Green Development

journal homepage: www.journals.elsevier.com/innovation-and-green-development

Full Length Article

# The influence of different environmental factors toward Vietnam's net-zero emissions goal

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A R T I C L E I N F O

*Keywords:*
Climate change
Energy use
Net-zero emissions
Technological innovation
Sustainable development

A B S T R A C T

Emissions of greenhouse gases (GHGs), especially carbon dioxide ($CO_2$), have an impact on the global climate, posing risks to environmental sustainability. Vietnam's economic growth and agricultural development have led to higher utilization of energy and emissions. Analyzing the trade-off between pollution and development in Vietnam can help mitigate environmental degradation while achieving Vietnam's goal of net-zero emissions by 2050. The research empirically investigates the effects of the economy, energy, technology, agriculture, and forestry on Vietnam's environmental quality. The study analyzed yearly data from 1990 to 2020 using the dynamic ordinary least squares (DOLS) technique. Empirical results show that as the economy and energy use rise, so do pollution. Conversely, a rise in technological innovation, agricultural productivity, and forest cover would reduce Vietnam's emissions. The stability of the DOLS results is observed when operating the canonical cointegrating regression (CCR) afterward fully modified least squares (FMOLS) techniques. To achieve its net-zero emissions goals and gain sustainable development, Vietnam should switch to cleaner energy, adopt low-carbon economies, encourage green technology innovation, use climate-smart farming methods, and reduce deforestation.

## 1. Introduction

The emissions of high levels of GHGs, specifically $CO_2$, are a very important concern regarding global warming. The main sources of these pollution are human actions involving the ignition of non-renewable energy and deforestation (Singh, 2022). Kemp et al. (2022) anticipate that the continuous boost in $CO_2$ emissions would have substantial and extensive implications for the worldwide climate system, resulting in severe costs that would affect various sectors of humanity. Promoting equitable growth and mitigating the adverse impacts of climate change are global priorities, while prioritizing the decrease of emissions and improving environmental quality (Islam et al., 2022). Hence, it is imperative to ascertain the key factors that impact emissions levels to enhance environmental conditions. Failure to address the interdependence involving contemporary methods for advancement and natural resource management will lead to environmental degradation (Raihan et al., 2024). Developing countries, like Vietnam, encounter various challenges concerning economic progression, energy security, technological innovation, agricultural output, forest cover, and ecological sustainability. However, Vietnam has formulated strategies to attain sustainable development. In an effort to combat climate change and minimize emissions, Vietnam accepted the Paris Agreement. Vietnam announced that it wants to achieve net zero emissions by 2050, despite grappling with notable environmental obstacles. An essential consideration for policymakers seeking to integrate climate change mitigation with sustainable development policies comprehends Vietnam's

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https://doi.org/10.1016/j.igd.2025.100229
Received 28 November 2023; Received in revised form 9 November 2024; Accepted 11 February 2025

susceptibility to climate change. Implementing measures that effectively address both objectives is essential. The simultaneous pursuit of pollution control and development presents a significant challenge. The topic of how Vietnam can cut its emissions is crucial. Evaluating the nation's ecological factors will help to tackle this problem.

Vietnam has undergone significant economic progression, succeeding from an impoverished country to a lower-middle-income territory (Nguyen et al., 2021). This country's GDP grew significantly, increasing almost thirty times from 14 billion US dollars in 1985 to 409 billion US dollars in 2022 (World Bank, 2024). In 2022, this country's economy achieved an 8 % annual GDP growth rate, positioning it as the most rapidly expanding economy in Southeast Asia among 34th globally (World Bank, 2024). Vietnam's economic development has resulted in increased power utilization, but it ended up bringing about several kinds of ecological problems (Hoa et al., 2023; Hung, 2023). Vietnam's heavy dependence on non-renewable energy, particularly coal and oil, is the main culprit for the nation's worsening environmental crisis (Nguyen & Le, 2022). And so, this area is extremely worried about the spike in $CO_2$ pollution concentrations, specifically in the energy sector. Thus, the economy-energy-environment nexus is crucial to comprehend.

The importance of novel strategies in addressing and mitigating global environmental degradation has been emphasized (Ahakwa et al., 2023). Proactive green technologies for cutting emissions remain in the works as a result of strict preservation standards. As the market is significantly dependent on these activities, the implementation of fresh financial processes becomes crucial for reforming and refining it. The reduction of industrial emissions can be accomplished by transitioning from a production-focused economic model to an innovation-focused one, thereby moving away from traditional patterns of economic development. The application of modern innovations has resulted in higher production levels and lower energy consumption in the global economy (Mughal et al., 2022). Decreasing the production costs makes this possible. Additionally, the introduction of new technologies facilitates the shift of the economy from conventional to alternative sources of energy, thereby satisfying its energy requirements (Shrestha et al., 2022). New technologies help reduce the use of energy and emissions from burning fossil fuels. The potential of technical advancements to modify and improve Vietnam's manufacturing system is an essential part of propelling the total growth of the country's economy. An examination of the implication of technology on Vietnam's ecosystem condition is necessary for promoting economic expansion and reducing emissions.

Agriculture has a substantial effect on ecological conditions. Land use, which encompasses changes in land, forestry events, and other land usage, accounts for approximately 20 % of annual emissions worldwide. Consequently, they are the second-biggest emitters and contribute greatly to the amplification of the warming planet. Vietnam's agricultural sector has made notable advancements over the past 25 years. The country plays a major role in the global market for agricultural commodities, including coffee and peanuts, besides rice. In Vietnam, farming is the main source of employment, with 18.8 million individuals employed in this sector in 2019 (Nguyen et al., 2021). Intensified agricultural output with ecological excellence is required to achieve green growth (Liu et al., 2022). According to Alhassan (2021), increased agricultural output has a beneficial effect on poverty reduction, food security, earnings allocation, and economic extension. Multiple investigations (Alhassan, 2021; Sarkar et al., 2022) have shown that improved agricultural output is favorable for environmental implications. The need for healthier products and services for the environment and the government's capacity to implement environmental laws are correlated with both agricultural output and economic expansion. The opposition to expanding cropland into forest areas is rooted in the belief that this practice is incompatible with adding agricultural value. This approach promotes forest conservation and mitigates pollution. The position of agricultural value added to sectors and ecological degradation has been acknowledged, and concerns regarding this matter are growing. Around 50 % of the world's forests are invaded, resulting in the depletion of groundwater supplies and the loss of biodiversity. The consequences mentioned can be linked to the increase in agricultural output and monetary expansion. Using fossil fuels for energy in farming annually releases billions of tons of GHGs, which leads to the acceleration of climatic issues (Wang et al., 2020). Studying how pollution is linked to agriculture is essential for developing effective sustainable agriculture policies.

The projected increase in global population will necessitate the expansion of infrastructure in various sectors, including food production, housing, agriculture, transportation, and others (Ouyang et al., 2022). This puts pressure on the world's diminishing forest resources. Increased carbon emissions in Southeast Asia are a result of deforestation, which is a result of a number of factors including urbanization, industrialization, and agricultural development (Roy et al., 2022). Lyu et al. (2023) discovered forests might act as suppliers of $CO_2$, causing a spike in climate change. Forest ecosystems globally sequester about 300 billion tons of $CO_2$ emissions annually, besides deforestation adds approximately 3 billion tons of $CO_2$ pollution to the environment each year. It is projected that global climate change will lead to an average global temperature increase of approximately 1.5 °C by 2050. Thus, forests are becoming more important in $CO_2$ removal through carbon sequestration. Therefore, a comprehensive global investigation is necessary to explore the consequences of forest cover (FC) on the release of $CO_2$ in Vietnam.

Globally, Vietnam falls into the 5 countries that are most prone to changes in the environment (ITA, 2024). A significant portion of the nation's population and finances reside along its broad, populated shoreline, which is often in danger from storms, droughts, hurricanes, and landslides (ITA, 2024). Moreover, this nation is grappling with a concerning issue of air pollution. Vietnam was placed 14th out of 118 countries in terms of air pollution levels in 2022 (ITA, 2024). Other environmental concerns in Vietnam include energy security, deforestation, and agricultural productivity. According to the government's forecast, Vietnam might potentially incur a loss of up to 11 % of its GDP by 2030 due to global warming and natural calamities. Given the detrimental impacts of climate change in Vietnam caused by increasing emissions intensity, it is imperative to adopt a novel and meticulous technique to foster the concerns by examining various environmental factors. Thus, the present investigation selected Vietnam as the research context to explore the impact of environmental factors on rising emissions. The findings from the investigation of the nexus between different environmental factors and Vietnam's emissions would provide new insights to policymakers for implementing appropriate policies to achieve the SDGs along with Vietnam's goal of net-zero emissions.

Multiple studies have examined the connection across $CO_2$ pollution and other variables in Vietnam. Nguyen and Le (2022) analyzed the link among green and non-green energy usage, $CO_2$ emissions, and income expansion in Vietnam. Tran (2022) investigated the correlation amongst Vietnam's economic progression, green finance, energy imports, renewable energy, and $CO_2$ pollution. Hoa et al. (2023) investigated the correlation among Vietnam's clean power, innovation, foreign direct investment (FDI), GDP expansion, and $CO_2$ emissions. Hung (2023) examines the causal relationships involving Vietnam's emissions of $CO_2$, globalization, and expansion of the economy. Despite being a globally significant dispute amongst current scholars, there is limited research in Vietnam on the environmental effects of agriculture and forestry. These sectors are the second-largest contributors to global emissions, following the energy sector. However, limited work examines the effects of natural elements on total GHG pollution, particularly in Vietnam. Henceforth, there exists a deficiency in the present literature that requires attention through a thorough econometric assessment. Seeking to address this gap, this study used econometric methods to assess the effects of economic progress, advancement in technology, agricultural output, and FC on $CO_2$ emissions and total GHG emissions in a setting in Vietnam. The main outcomes indicate an encouraging relationship among GDP development and increased pollution. Conversely, it suggests that long-term reductions in Vietnam's emissions can be achieved through advancements in technical innovation, agricultural productivity, and forest cover. A number of diagnostic tests, such as unit root tests, DOLS, FMOLS, and CCR analysis were adopted to make sure the results were correct.

This study endeavors to make significant additions to the existing body of research regarding Vietnam's policies in an assortment of methods. The recent studies examined emissions of $CO_2$ as a pollution indicator in Vietnam (Hoa et al., 2023; Hung, 2023) as well as in the world's leading polluting economies (Saqib et al., 2024a), including China and the United States (Saqib and Usman, 2023). In contrast, the present research is innovative in its use of total emissions of GHG as a display of environmental pollution. Our work delivers a novel understanding of the connection between environmental factors and emissions of GHGs, particularly in developing countries such as Vietnam. Previous empirical studies (Saqib et al., 2023; Hung, 2023; Hoa et al., 2023; Saqib et al., 2024b) did not look at how the agriculture and forestry sectors affected the environment or use relevant indicators in their econometric model. This study, on the other hand, looks at how these sectors affect Vietnam's emissions.

Furthermore, although the previous studies investigated the association across Vietnam's $CO_2$ emissions and its determinants, past studies only focused on specific policy recommendations for environmental and economic development. For example, Nguyen and Le (2022) suggested policy implications to expand the influence of power utilization and $CO_2$ releases on Vietnam's economic development. Tran (2022) offered broad plans encompassing GDP growth, green commercial techniques, environmental health, and the mitigation of $CO_2$ emissions. In their study, Hoa et al. (2023) put up a set of proposals aimed at facilitating the growth of a healthy and green economy in Vietnam. The policy reforms made by Hung (2023) encompass multiple steps, including encouraging investment, supporting sound governance, and promoting human resource creation. However, our research makes a significant contribution to the field of innovation and sustainability. It suggests effective strategies for green innovation, green economy, green energy, green agriculture, green forestry, and environmental policies.

Moreover, the research's findings could guide policymakers with effective visions for formulating actual strategies aimed at reaching net zero emissions in Vietnam by 2050. The exact goals include achieving zero hunger through increased agricultural production (SDG 2), promoting better health besides well-being by reducing emissions (SDG 3), ensuring affordable and clean energy by reducing fossil fuel usage and promoting renewable energy (SDG 7), fostering sustainable economic growth through a low-carbon economy (SDG 8), advancing industry, innovation, besides infrastructure (SDG 9), promoting sustainable communities with reduced pollution (SDG 11), inspiring responsible consumption and production (SDG 12), enchanting climate action through emission reduction (SDG 13), and preserving life on land through climate-smart agriculture and sustainable forest management (SDG 15). This investigation's findings have practical implications for evaluating and shaping environmental policies in Vietnam. Implications arise from the necessity to enhance policy and action plans for mitigating climate change impacts, with the aim of preparing the country for a 1.5 °C world. The findings can assist Vietnam in showing a balanced relationship involving sustainable development with the mitigation of environmental pollution. This report's outcomes may provide direction to other emerging nations aiming to formulate effective approaches for fostering green ecosystems and improve efforts in adapting to and mitigating global warming.

## 2. Methodology

### 2.1. Data

The analysis utilized time series data from 1990 to 2020 for Vietnam, taken from the World Development Indicators (WDI). The dataset used for the analysis does not include data from the time following 2020, as there is a lack of information regarding technological innovations beyond that year. Besides, the study intended to exclude the effects of the COVID-19. The study examined $CO_2$ emissions and total GHG emissions as dependent variables and economy, energy, technology, agriculture, and forest as independent variables. The variables were logarithmically transformed to achieve a normal distribution of the data. Table 1 displays all variables information. Fig. 1 illustrates the yearly trends of the examined variables.

### 2.2. Theoretical framework and model generation

Increased releases of $CO_2$ are theoretically linked to higher GDP progress as well as energy consumption. The current study created an economic function at time "t" based on the standard Marshallian demand function (Friedman, 1949). This formula simulates a market clearing situation where growth in emissions is equal to growth in the economy and energy consumption.

$$CO_{2t} = f\,(GDP_t;\, EU_t) \tag{1}$$

The Marshallian demand function provides a precise rationalization of the standard demand function. The resolution addresses the utility maximization dilemma faced by consumers, aiming to extend their efficacy and specify their profits and costs. The Marshallian demand function is commonly employed in microeconomics and macroeconomics. This function aims to explore consumer behavior in a market and assist firms in making pricing decisions. Policymakers can gain insight into managing economic fluctuations by studying the relationship between price changes and demand. Therefore, this study employed this novel function to analyze the implication of independent variables on $CO_2$ pollution in Vietnam.

Technological changes and innovations impact a country's economic growth and energy consumption patterns. Technological advancements may lead to higher growth of the economy and usage of energy. Green technology innovations aim to increase energy efficiency and reduce emissions. Consequently, it is a priority to assess the environmental repercussions of high-tech advancements. The agriculture and forestry sectors contribute to emissions through land degradation and deforestation. Given the significant contributions of the forestry and agricultural sectors to environmental sustainability, it is important to examine their impacts. Therefore, the study estimated two models ($CO_2$ model and GHG model) presented below that incorporates technological innovations, agricultural productivity, and forest cover.

$$\text{Model 1}: LCO2_t = \tau_0 + \tau_1 LGDP_t + \tau_2 LEU_t + \tau_3 LTI_t + \tau_4 LAVA_t + \tau_5 LFC_t + \varepsilon_t \tag{2}$$

$$\text{Model 2}: LGHG_t = \tau_0 + \tau_1 LGDP_t + \tau_2 LEU_t + \tau_3 LTI_t + \tau_4 LAVA_t + \tau_5 LFC_t + \varepsilon_t \tag{3}$$

**Table 1**
Variables' description.

| Variables | Description | Logarithmic structure | Units |
|---|---|---|---|
| $CO_2$ | $CO_2$ emissions | LCO2 | Kilotons (Kt) |
| GHG | Total GHG emissions | LGHG | Kt of $CO_2$ equivalent |
| GDP | Economic growth | LGDP | Constant Vietnamese Dong |
| EU | Energy use | LEU | Kg of oil equivalent per capita |
| TI | Technological innovation | LTI | Number of patent applications |
| AVA | Agricultural value added | LAVA | Percentage of GDP |
| FC | Forest cover | LFC | Square kilometers |

Note: Data for all the variables were collected from the WDI database created by the World Bank (2024)

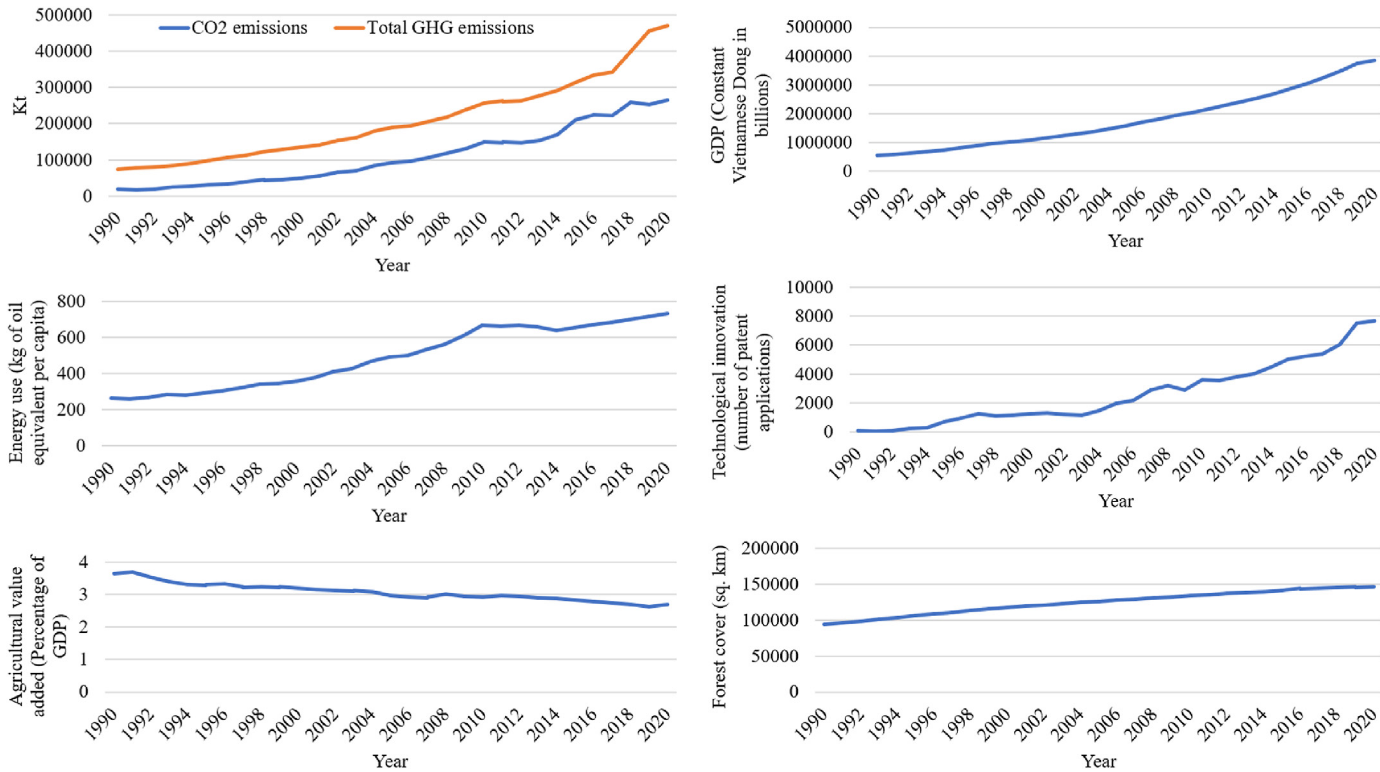


**Fig. 1.** Yearly trends of the variables.

where $\tau_0$ and $\varepsilon_t$ are the intercept and error term whereas $\tau_1$, $\tau_2$, $\tau_3$, and $\tau_4$ are the coefficients.

The estimated models have been justified in light of the previous literature on this specific topic investigating the influences of economy, energy, technology, agriculture, and forestry on environmental sustainability. For example, Waheed et al. (2018) explored the influences of renewable energy, agriculture, and forest on $CO_2$ emissions in Pakistan. Koondhar et al. (2021) investigated the dynamic impacts of renewable energy, forestry, and agriculture on China's carbon emission. Usman and Makhdum (2021) explored the effects of agriculture, forest, non-renewable and renewable energy consumption on environmental degradation in BRICS-T countries. Raihan et al. (2022) examined the influences of the economy, renewable energy, technological innovation, and forests on $CO_2$ emissions in Bangladesh. Furthermore, Raihan et al. (2023) explored the emission reduction potential of the economy, renewable energy, technology, and forests in Indonesia. Besides, Raihan (2023) examined the emission reduction potential of the economy, renewable energy, technological innovation, and forests in Colombia by using both $CO_2$ and GHG emission models. The analysis procedures utilized in the present study are given in Fig. 2.

### 2.3. Data stationarity tests

Conducting a unit root investigation is vital for averting false regression assumptions. The first step involves utilizing stationary methods to approximate the equation. The stationarity of the variables is verified prior to estimating the regression equation. Multiple researchers widely recognized that specifying the integration sequence is necessary for discussing cointegration (Raihan & Tuspekova, 2022). Several studies recommend using multiple unit root examinations to evaluate the integration sequence of a series (Raihan et al., 2025). The Augmented Dickey-Fuller (ADF) (Dickey & Fuller, 1979), the Dickey-Fuller generalized least squares (DF-GLS) (Elliott et al., 1992), and the Phillips-Perron (P-P) methods (Phillips & Perron, 1988) were employed in our research.

### 2.4. DOLS regression

We applied the DOLS technique, which is an extension of the OLS estimate equation (Stock & Watson, 1993), to analyze the data. This technique incorporates illuminating factors and their respective leads and lags of the initial difference terms. The purpose of this is to reduce the influence of indigenous factors and to compute standard deviations using a covariance matrix that is unaffected by serial correlation. The DOLS procedure enables the integration of distinct variables in a mixed sequence of integration within the integrated outline. This process entails estimating the variables associated with explanatory factors at different times, including leads, levels, and lags. This estimation method addresses challenges related to indigeneity, autocorrelation, and small sample bias by considering the effects of different explanatory factors over time (Begum et al., 2020). The investigation continues by using Equations (4) and (5) to perform DOLS calculation of the long-run coefficient. This is done after making sure that the data is stationary.

$$\begin{aligned}\Delta LCO2_t = {} & \tau_0 + \tau_1 LCO2_{t-1} + \tau_2 LGDP_{t-1} + \tau_3 LEU_{t-1} + \tau_4 LTI_{t-1} \\ & + \tau_5 LAVA_{t-1} + \tau_6 LFC_{t-1} + \sum_{i=1}^{q} \gamma_1 \Delta LCO2_{t-i} + \sum_{i=1}^{q} \gamma_2 \Delta LGDP_{t-i} \\ & + \sum_{i=1}^{q} \gamma_3 \Delta LEU_{t-i} + \sum_{i=1}^{q} \gamma_4 \Delta LTI_{t-i} + \sum_{i=1}^{q} \gamma_5 \Delta LAVA_{t-i} \\ & + \sum_{i=1}^{q} \gamma_6 \Delta LFC_{t-i} + \varepsilon_t \end{aligned} \tag{4}$$

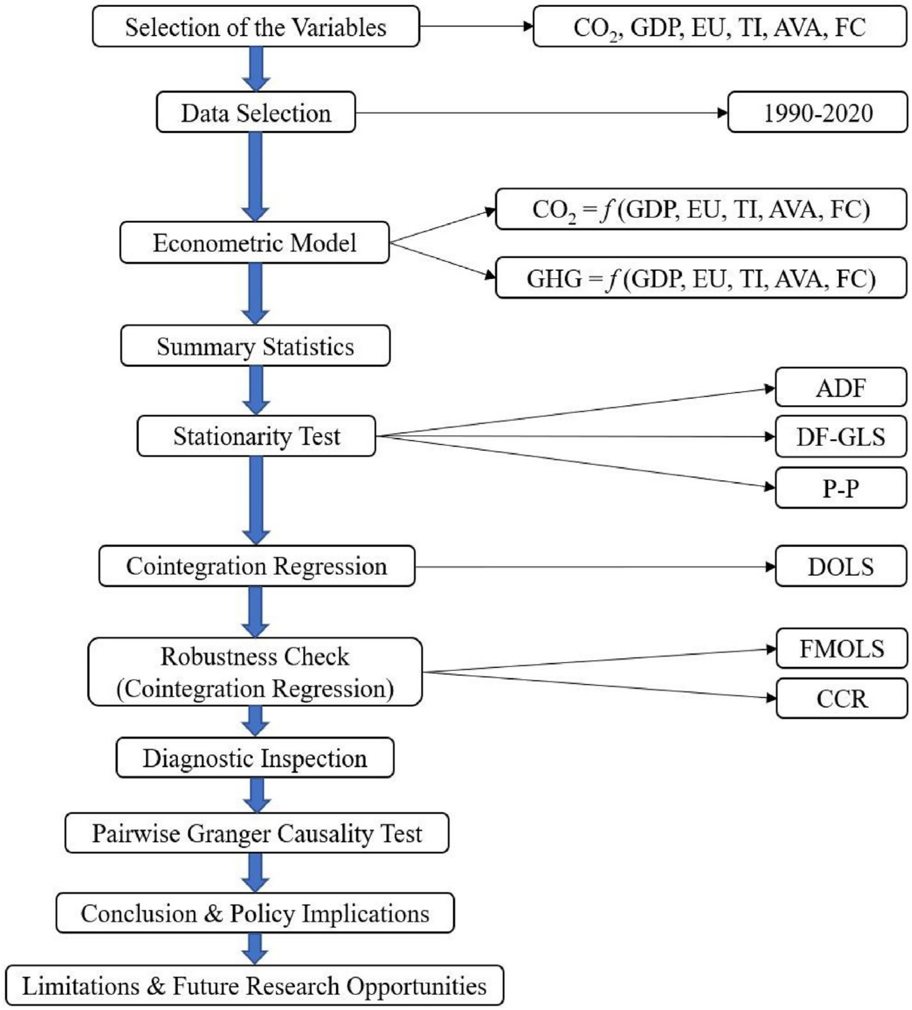


**Fig. 2.** Flow chart of the analysis.

$$\begin{aligned}\Delta LGHG_t = {} & \tau_0 + \tau_1 LGHG_{t-1} + \tau_2 LGDP_{t-1} + \tau_3 LEU_{t-1} + \tau_4 LTI_{t-1} \\ & + \tau_5 LAVA_{t-1} + \tau_6 LFC_{t-1} + \sum_{i=1}^{q} \gamma_1 \Delta LGHG_{t-i} + \sum_{i=1}^{q} \gamma_2 \Delta LGDP_{t-i} \\ & + \sum_{i=1}^{q} \gamma_3 \Delta LEU_{t-i} + \sum_{i=1}^{q} \gamma_4 \Delta LTI_{t-i} + \sum_{i=1}^{q} \gamma_5 \Delta LAVA_{t-i} + \sum_{i=1}^{q} \gamma_6 \Delta LFC_{t-i} \\ & + \varepsilon_t\end{aligned} \tag{5}$$

Where, $\Delta$ is the first difference operator and q is the optimum lag length.

### 2.5. Robustness check

The fully modified OLS (FMOLS) and Canonical Cointegrating Regression (CCR) assessments were used in this study to check how stable the DOLS conclusions were. Hansen and Phillips (1990) proposed the FMOLS regression model for improved cointegration regression analyses. The FMOLS method offers the least squares method to handle problems related to serial correlation besides endogeneity in endogenous parameters created from cointegration. Park (1992) introduced the CCR procedure, which uses cointegrating modeling to transform data by focusing on the stationary component. The cointegrating link in the cointegrating paradigm remains constant during data handling. In a cointegration assessment model, the CCR transformation is used to make sure that the standard error has a normal distribution and that the regression coefficients have no instances. An ergodic chi-square statistic and a linearly effective estimate method are both produced by the CCR method, without the need for nuisance parameters. The application of FMOLS and CCR techniques can lead to consistent exponential growth by studying the stimulus of serial correlation.

### 2.6. Causality test

This study applied the pairwise Granger-causality test (Granger, 1969) to probe the causal link within the factors. It delivers multiple benefits upon alternative time-series assessment techniques. This method has ability to analyze a large number of lags while ignoring higher-order lags. Using F tests, it is possible to determine Granger causality between variables X and Y while using the Ordinary Least Squares (OLS) test to estimate coefficients. The time series for this pair of variables is represented as $X_t$ and $Y_t$, where $X_t$ and $Y_t$ indicate their respective values at time t. Nevertheless, a bivariate autoregressive model can demonstrate the variables $X_t$ and $Y_t$.

$$X_t = \beta_1 + \sum_{i=1}^{n} \alpha_i Y_t -_i + \sum_{i=1}^{n} \mu_i X_t -_1 + e_t \tag{6}$$

$$Y_t = \beta_2 + \sum_{i=1}^{n} \Omega_i Y_t -_1 + \sum_{i=1}^{n} \infty_i X_t -_i + u_t \tag{7}$$

where "n" is the number of lags while "$e_t$" and "$u_t$" are the residual factors.

## 3. Results

### 3.1. Summary statistics

The synopsis statistics of variables' normality tests with skewness, kurtosis, Jarque-Bera, and probability are exhibited in Table 2. The dataset for Vietnam includes 31 observations for each variable, spanning from 1990 to 2020. Values for skewness that are near zero suggest that variables follow a normal distribution. The kurtosis statistic suggests that all series display platykurtic characteristics, with values consistently below the critical threshold of 3. Also, the Jarque-Bera probability examination confirms that variables fall within the normal range.

### 3.2. Results of unit root tests

To maintain the accuracy of the investigation, each variable was individually assessed to ensure that none of them exceeded the integration order. The additional details of the unit root evaluations conducted using the ADF, DF-GLS, and P-P assessments are described in Table 3. The null hypothesis is the existence of a unit root, which indicates that the data is not stationary. Instead, the alternative hypothesis is the stationary root of the data. If the p-value is below 0.05, the null hypothesis can be rejected. Moreover, findings reveal the stationarity of data in all three unit root tests with first-order integration. Hence, the DOLS tactic can serve as a better option than conventional cointegration processes.

### 3.3. Results of DOLS estimation

Table 4 exhibits the DOLS estimated influences of several factors on $CO_2$ and GHG releases in Vietnam over the long term. The projected LGDP coefficients are positively associated with emissions. These findings indicate that a 1 % expansion in economy causes a 0.89 % growth in $CO_2$ emissions and a 0.58 % spike in GHG pollution. It shows that financial progress is associated with ecological damage. Furthermore, the coefficients of LEU are significant at a 1 % threshold. The findings suggest that an extra 1 % rise in power consumption is linked to a 1.75 % surge in $CO_2$ emissions and a 1.36 % boost in GHG emissions. These findings indicate that prolonged energy consumption adversely affects the quality of the environment. Nonetheless, the coefficients of technological innovation are statistically significant and positive. It demonstrates that a 1 % upsurge in TI is coupled with a 0.08 % cut in $CO_2$ pollution and a 0.11 % drop in GHG emissions.

Furthermore, the projected coefficients for agricultural value added exhibit statistical significance and a negative relationship. The findings indicate that a 1 % expansion in agricultural output creates a 0.28 % decrease in $CO_2$ emissions and a 0.29 % fall in GHG emissions. The study demonstrates that agricultural value added in Vietnam plays a role in improving the natural health through the absorption of atmospheric $CO_2$ by cropland and its subsequent storage as biomass carbon. The study concludes that the coefficients of forest cover areas are significant at 1 %. The results imply that a 1 % expansion in forest extent is linked to a 1.47 % mitigation in $CO_2$ emissions and a 1.33 % cut in GHG emissions. These facts illustrate that power usage and GDP growth have adverse effects on the planet, but that pollutants can be reduced through advances in technology, agricultural value addition, and forest cover in Vietnam.

In addition, the predicted coefficients demonstrate consistency in both conceptual understanding and practical application. This study employed diagnostic examinations to evaluate the adequacy of the assessed model. The $R^2$ and adjusted $R^2$ values of the $CO_2$ model (0.97) and GHG model (0.99) indicate a robust fit of the regression model.

### 3.4. Results robustness check with FMOLS and CCR

The results shown in Tables 5 and 6 from the FMOLS and CCR analyses support the idea that the DOLS approximation is strong. The findings of FMOLS and CCR support a significant and beneficial link of GDP expansion and energy intake with $CO_2$ and GHG emissions in Vietnam. The study's results provide additional evidence supporting the negative connection of TI, AVA, and FC with $CO_2$ and GHG emissions. So, it is inferred that economic progress and energy use are factors that contribute to Vietnam's emissions. Conversely, technological innovation, agricultural output, and forest expansion play a role in helping Vietnam achieve its objective of reaching net-zero emissions. The outcome of the FMOLS and CCR models is consistent with the conclusions of the DOLS analysis. The R2 and adjusted R2 estimates from FMOLS and CCR assumptions show how well the model fits the data. They show that the

**Table 2**
Descriptive statistics.

| Variables | LCO2 | LGHG | LGDP | LEU | LTI | LAVA | LFC |
|---|---|---|---|---|---|---|---|
| Mean | 11.30 | 12.10 | 34.97 | 6.18 | 7.32 | 3.08 | 11.72 |
| Median | 11.43 | 12.15 | 35.00 | 6.20 | 7.57 | 3.02 | 11.74 |
| Maximum | 12.74 | 13.06 | 35.89 | 6.88 | 8.95 | 3.70 | 11.89 |
| Minimum | 9.82 | 11.20 | 33.94 | 5.56 | 4.13 | 2.64 | 11.45 |
| Skewness | −0.18 | −0.02 | −0.13 | 0.05 | −0.08 | 0.05 | −0.49 |
| Kurtosis | 1.89 | 1.91 | 1.87 | 1.65 | 1.40 | 1.66 | 2.09 |
| Jarque-Bera | 1.75 | 1.55 | 1.75 | 2.38 | 2.20 | 1.42 | 2.29 |
| Probability | 0.42 | 0.46 | 0.42 | 0.31 | 0.41 | 0.49 | 0.32 |

Note: Number of observations for each variable = 31.

**Table 4**
Results of DOLS test.

| Variables | Dependent variable: LCO2 | | | Dependent variable: LGHG | | |
|---|---|---|---|---|---|---|
| | Coefficient | t-Statistic | p-value | Coefficient | t-Statistic | p-value |
| LGDP | 0.89** | 2.27 | 0.04 | 0.58*** | 4.29 | 0.00 |
| LEU | 1.75*** | 4.28 | 0.00 | 1.36*** | 7.15 | 0.00 |
| LTI | −0.08* | −1.92 | 0.08 | −0.11** | −2.89 | 0.03 |
| LAVA | −0.28** | −3.52 | 0.01 | −0.29* | −1.94 | 0.06 |
| LFC | −1.47*** | −4.04 | 0.00 | −1.33*** | −4.88 | 0.00 |
| C | 10.53 | 1.23 | 0.23 | 9.58 | 1.19 | 0.25 |
| $R^2$ | 0.97 | | | 0.99 | | |
| Adjusted $R^2$ | 0.97 | | | 0.99 | | |

Note: ***p < 0.01, **p < 0.05, and *p < 0.1.

**Table 3**
Results of unit root tests.

| Logarithmic form of the variables | ADF | | DF-GLS | | P-P | |
|---|---|---|---|---|---|---|
| | Log levels | Log first difference | Log levels | Log first difference | Log levels | Log first difference |
| LCO2 | −0.39 | −5.22*** | 0.07 | −4.16*** | −0.61 | −5.41*** |
| LGHG | 0.98 | −4.73*** | 0.20 | −4.64*** | 0.54 | −4.72*** |
| LGDP | −1.94 | −3.39** | −1.21 | −2.96** | −1.94 | −2.98** |
| LEU | 0.73 | −5.61*** | 0.34 | −4.46*** | 0.98 | −7.61*** |
| LTI | −2.60 | −4.08*** | −0.30 | −3.47*** | −2.60 | −4.28*** |
| LAVA | −1.84 | −4.94*** | −0.12 | −3.90*** | −2.65 | −4.98*** |
| LFC | −1.20 | −10.19*** | −0.36 | −6.62*** | −1.71 | −10.36*** |

Note: ***p < 0.01, **p < 0.05.

**Table 5**
Results of FMOLS test.

| Variables | Dependent variable: LCO2 | | | Dependent variable: LGHG | | |
|---|---|---|---|---|---|---|
| | Coefficient | t-Statistic | p-value | Coefficient | t-Statistic | p-value |
| LGDP | 0.90** | 3.01 | 0.02 | 0.61*** | 4.27 | 0.00 |
| LEU | 1.74*** | 4.19 | 0.00 | 1.39*** | 7.02 | 0.00 |
| LTI | −0.09* | −1.94 | 0.06 | −0.13** | −2.64 | 0.03 |
| LAVA | −0.27** | −2.70 | 0.03 | −0.29* | −1.92 | 0.06 |
| LFC | −1.48*** | −3.12 | 0.00 | −1.36*** | −3.28 | 0.00 |
| C | 10.43 | 1.28 | 0.21 | 8.79 | 1.12 | 0.28 |
| $R^2$ | 0.97 | | | 0.99 | | |
| Adjusted $R^2$ | 0.97 | | | 0.99 | | |

Note: ***$p < 0.01$, **$p < 0.05$, and *$p < 0.1$.

**Table 6**
Results of CCR test.

| Variables | Dependent variable: LCO2 | | | Dependent variable: LGHG | | |
|---|---|---|---|---|---|---|
| | Coefficient | t-Statistic | p-value | Coefficient | t-Statistic | p-value |
| LGDP | 0.86** | 2.58 | 0.03 | 0.58*** | 4.38 | 0.00 |
| LEU | 1.78*** | 3.72 | 0.00 | 1.37*** | 7.09 | 0.00 |
| LTI | −0.09* | −1.89 | 0.08 | −0.12** | −2.22 | 0.04 |
| LAVA | −0.26*** | −3.03 | 0.00 | −0.29** | −1.99 | 0.04 |
| LFC | −1.49*** | −3.92 | 0.00 | −1.35*** | −3.63 | 0.00 |
| C | 9.62 | 0.97 | 0.34 | 8.37 | 1.85 | 0.14 |
| $R^2$ | 0.97 | | | 0.99 | | |
| Adjusted $R^2$ | 0.97 | | | 0.99 | | |

Note: ***$p < 0.01$, **$p < 0.05$, and *$p < 0.1$.

**Table 7**
Results of diagnostic tests.

| Diagnostic tests | Model: $CO_2$ | | Model: GHG | | Decision |
|---|---|---|---|---|---|
| | Coefficient | p-value | Coefficient | p-value | |
| Jarque-Bera test | 1.13 | 0.54 | 0.37 | 0.83 | Normally distributed residuals |
| Breusch-Godfrey LM test | 1.62 | 0.21 | 1.64 | 0.21 | No serial correlation |
| Breusch-Pagan-Godfrey test | 1.43 | 0.19 | 1.43 | 0.26 | No heteroscedasticity |

Note: LM = Lagrange Multiplier.

exogenous factors can explain 97 % of the differences in the change of the dependent variable.

### 3.5. Results of diagnostic tests

Table 7 summarizes the diagnostic test outcome, showing that the model's outcomes follow a normal distribution in the absence of autocorrelation or heteroscedasticity in the dataset. To enhance the model's reliability, the investigation performed the cumulative sum of recursive residuals (CUSUM) and CUSUM square tests. Fig. 3 presents the CUSUM and CUSUM square plots for the data, using a 5 % significance level. The line graph exhibits the model's stability at a 5 % significance threshold by plotting residuals as blue lines and confidence intervals as red lines.

### 3.6. Results of causality test

The results of the pairwise Granger causality test are shown in Table 8. It also shows the directions of causality from left to right (→) and from right to left (↔), which means that two parameters can cause each other. The findings suggest that one-way causality exists from LGDP to LCO2, LEU to LCO2, LCO2 to LTI, LAVA to LCO2, LAVA to LGDP, LFC to LGDP, LTI to LEU, LAVA to LEU, LTI to LAVA, and LFC to LAVA. This is because the F-statistic values are too high to reject the $H_0$. It suggests that GDP growth, power utilization, and agricultural value added generate more $CO_2$; $CO_2$ releases affect technical innovation; agricultural value added and forest cover expand the economy; technological advancement causes energy use and agricultural value added; agricultural value added causes power consumption; and forest cover causes agricultural value added. The results also show that LGDP has a two-way effect on LEU and LTI, since statistically significant F-statistic values mean that the $H_0$ is not true in both directions. Therefore, the bidirectional causality regarding energy utilization and GDP expansion indicates that the variables accelerate to each other. Similarly, economic growth and technological innovation influence each other. However, the investigation found no causal link among forest cover and $CO_2$ emissions, energy use, or innovations. Fig. 4 illustrates the graphical representation of the causal relationship across the factors.

## 4. Discussion

The research observes an encouraging significant correlation between long-term monetary progress and Vietnam's rising emissions. Our conclusions are agreed with Tran (2022), Hung (2023), Shahbaz et al. (2019), Nguyen et al. (2021), and Hoa et al. (2023), they explored a beneficial link involving GDP and releases of $CO_2$ in Vietnam. Nonetheless, financial activities can coexist with ecological safeguards and conservation, rather than jeopardizing enduring ecological excellence. Vietnam revised its national environmental protection law in 2014 to align with achieving SDGs. The cap-and-trade policy approach establishes a domestic carbon credit market. The policy imposes emissions limits on corporations and permits them to trade surplus credits with other firms. This system aids in cost reduction for companies that stay within their emission limits. Nguyen et al. (2021) state that companies must notify the appropriate agency regarding their emission levels in order to comply with the proportion.

We also established a significantly positive effect of power usage on Vietnam's long-term emission levels. Our findings are consistent with earlier research in Vietnam by Shahbaz et al. (2019), Nguyen et al. (2021), Phong et al. (2018), and Tran (2022). This analysis shows that fossil fuels are responsible for harmful pollutants in Vietnam and the country's primary energy supply. Vietnam has developed a national energy plan that prioritizes the growth of fossil-fuel-based industries, given its status as a producer of oil and coal. Industrial and residential activities significantly impact the environment negatively. The depletion of these resources due to overexploitation would render economic progress dependent on fossil fuels unsustainable. Vietnamese officials plan to develop a strategy to decrease the reliance on coal-fired fuel and reduce energy-related emissions by 15 % by 2030. Vietnam has been proactive in its efforts to achieve a low-carbon energy system via policy implementation and technological utilization, with the aim of reaching net-zero emissions by 2050.

Coal-fired power plants in Vietnam play a major position in the country's electrical energy production, representing around 50 % of the total. The use of coal raises concerns regarding emissions of GHG plus their potential consequences on human and ecological health (Raihan & Bari, 2024). Therefore, it is urgent to establish of a resilient clean energy infrastructure that will eventually replace coal. Vietnam has prioritized the advancement of renewable energy since the early 2000s, while coal-based energy production stays unmovable. The use of green power sources is needed to achieve equitable growth and address the pressing issue of climate change (Raihan & Tuspekova, 2023). Renewable energies provide financial gains, including reducing emissions. The evolution of Vietnam's energy mix to include renewable supplies is vital in response to the growing universal conservation consciousness. This

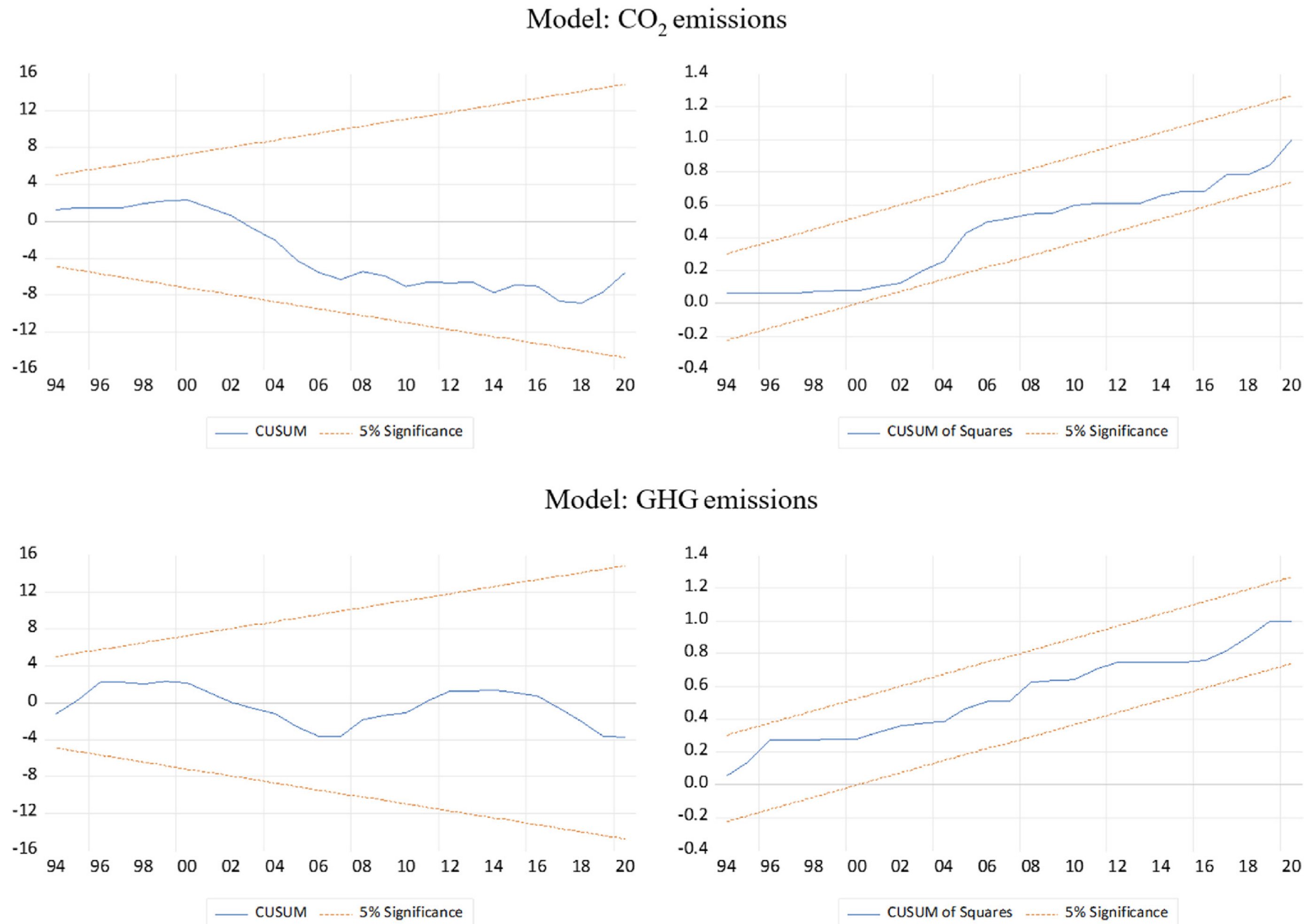


**Fig. 3.** Results of the CUSUM and CUSUM square tests.

transition will promote green energy and the creation of a sustainable ecology. Nevertheless, various technological, functional, social, and financial constraints have impeded the sustainable exploitation and utilization of these resources. Vietnam obliges a thorough scheme to effectively advance renewable energy generation to successfully reaching to a low-carbon economy.

This study investigated the potential benefits for Vietnam in terms of improved technical innovation in the field of environmental protection. The coefficient for technological innovation is found to have a significant negative association with emissions. The embracing of eco-friendly technologies in Vietnam's manufacturing segment could improve the nation's environmental condition by reducing emissions. Chu et al. (2021) identified a destructive association concerning technological innovation and $CO_2$ pollution in Vietnam. However, our outcomes also explored that technological innovation is less effective in reducing emissions compared to agricultural productivity and forest cover. Vietnam's current emphasis on researching and developing low-carbon technology seems inadequate. Vietnam can attain its net-zero emissions goal through the acceptance of environmentally friendly technologies coupled with the stimulation of sustainable economic development. The implementation of modern technology can assist Vietnam in achieving its intention of practicing sustainable green growth.

This paper observed a substantial detrimental link between agricultural output and Vietnam's rising pollution. Agricultural efficiency improves environmental quality through the capacity of cropland to sequester atmospheric $CO_2$ as biomass besides soil carbon. The results of the research align with prior research conducted in Vietnam (Shahbaz et al., 2019). Our research indicates that adopting modern technologies in Vietnam's agriculture sector would lead to increased agricultural value added, reduced emissions, and sustained food security. Reducing agricultural GHG emissions through the adoption of appropriate farming practices could have the dual benefits of improving the environment and creating additional income opportunities through expanded farming operations. Agricultural operations can reduce their carbon footprint by implementing suitable management practices and utilizing advanced technology to store carbon emissions effectively. International organizations have created climate-smart agriculture (CSA) as a means of reducing the harm that agricultural practices cause to the environment. These projects have significant long-term implications for reducing and mitigating global climate change.

The Vietnamese government aims to simultaneously achieve preservation of natural resources, expansion of agricultural production, enhancement of farmer incomes, and revitalization of rural areas. The government implemented substantial revisions to key documents in 2020, which specifies the foundation for current strategies for combating climate change in the agricultural and rural sectors. An action plan has been formulated by the agricultural sector for the period 2021–2030 to tackle climate change, in addition to a long-term vision for 2050. The government's goal is to gain a 20 % fall in GHG emissions in rural and agricultural regions on a yearly basis. This will be accomplished through the implementation of crop and animal husbandry practices, including the adoption of CSA.

Moreover, the scrutiny's findings hint that deforestation elevated $CO_2$ emissions and plays a noteworthy role in worldwide temperature rise.

**Table 8**
The findings of the pairwise Granger causality test.

| $H_0$ | F-statistic | Decision on $H_0$ | Direction of causality |
|---|---|---|---|
| LGDP ≠ LCO2 | 2.79** | Reject | LGDP → LCO2 |
| LCO2 ≠ LGDP | 0.25 | Accept | |
| LEU ≠ LCO2 | 2.83** | Reject | LEU → LCO2 |
| LCO2 ≠ LEU | 0.66 | Accept | |
| LTI ≠ LCO2 | 0.47 | Accept | LCO2 → LTI |
| LCO2 ≠ LTI | 1.78* | Reject | |
| LAVA ≠ LCO2 | 1.94* | Reject | LAVA → LCO2 |
| LCO2 ≠ LAVA | 0.54 | Accept | |
| LFC ≠ LCO2 | 0.35 | Accept | LFC ≠ LCO2 |
| LCO2 ≠ LFC | 0.29 | Accept | |
| LEU ≠ LGDP | 3.97** | Reject | LEU ↔ LGDP |
| LGDP ≠ LEU | 4.98*** | Reject | |
| LTI ≠ LGDP | 1.45* | Reject | LTI ↔ LGDP |
| LGDP ≠ LTI | 1.59* | Reject | |
| LAVA ≠ LGDP | 2.79** | Reject | LAVA → LGDP |
| LGDP ≠ LAVA | 0.46 | Accept | |
| LFC ≠ LGDP | 1.43* | Reject | LFC → LGDP |
| LGDP ≠ LFC | 0.55 | Accept | |
| LTI ≠ LEU | 5.25*** | Reject | LTI → LEU |
| LEU ≠ LTI | 0.68 | Accept | |
| LAVA ≠ LEU | 2.29** | Reject | LAVA → LEU |
| LEU ≠ LAVA | 0.99 | Accept | |
| LFC ≠ LEU | 0.48 | Reject | LFC ≠ LEU |
| LEU ≠ LFC | 0.33 | Reject | |
| LAVA ≠ LTI | 0.76 | Accept | LTI → LAVA |
| LTI ≠ LAVA | 5.53*** | Reject | |
| LFC ≠ LTI | 0.77 | Accept | LFC ≠ LTI |
| LTI ≠ LFC | 0.86 | Accept | |
| LFC ≠ LAVA | 2.69** | Reject | LFC → LAVA |
| LAVA ≠ LFC | 0.85 | Accept | |

***$p < 0.01$, **$p < 0.05$, and *$p < 0.1$.

The forest cover in Vietnam is essential for $CO_2$ mitigation through sequestration in plant biomass and incorporation into the soil, improving the country's environmental conditions. The empirical research suggests that increasing tree coverage is the most effective long-term strategy for mitigating environmental degradation. Deforestation is the second-major cause of pollution in the atmosphere. Halting land clearing for agriculture and other purposes is a straightforward approach to reducing $CO_2$ emissions. Enhancing tree carbon storage is a highly proficient and lucrative strategy for avoiding pollution. These efforts are considered essential for mitigating climate change. Forestry mitigation strategies, including forest preservation, tree planting, and natural regeneration, have multiple benefits, including preserving biodiversity, developing ecosystems, producing commodities and services for communities, and sequestering carbon. It is crucial to reduce emissions in all sectors, enhance the country's carbon sink capacity, and implement large-scale forest-based mitigation techniques to protect the ecosystem condition. The expansion of forest cover in Vietnam has the potential to significantly decrease the country's emissions, achieving carbon neutrality.

## 5. Conclusion and policy implications

### 5.1. Conclusion

The investigation explores the impact of GDP outgrowth, energy consumption, advances in technology, agricultural efficiency, and forest coverage on rising pollutants in Vietnam. This study adopted the DOLS technique to probe the persistent liaison involving the variables. The analysis utilized Vietnam's data, spanning from 1990 to 2020. The series' integration order is determined via ADF, DF-GLS, and P-P unit root assessments. Our findings indicate a beneficial connection among GDP progress and energy use and emissions and a potential reduction in Vietnam's emissions in the long term through increased technical innovation, agricultural productivity, and forest cover. The assessed findings are robust when using FMOLS and CCR methods. Furthermore, the pairwise Granger causality examination is conducted to investigate the causal relationships among the factors. The current inquiry attempts to solve an emerging knowledge deficit by looking at the potential consequences of technological advances, agricultural value-added, and forest cover in conjunction with Vietnam's objective of achieving zero net emissions. The study at hand discusses suggestions for policies aimed at fostering environmentally conscious growth through the execution of rigorous monitoring strategies that effectively mitigate environmental damage.

### 5.2. Policy implications

The paper deploys that Vietnamese legislators should establish an ecological guideline that effectively cuts emissions while maintaining economic progress. To address pollution, it is a priority to reassess the

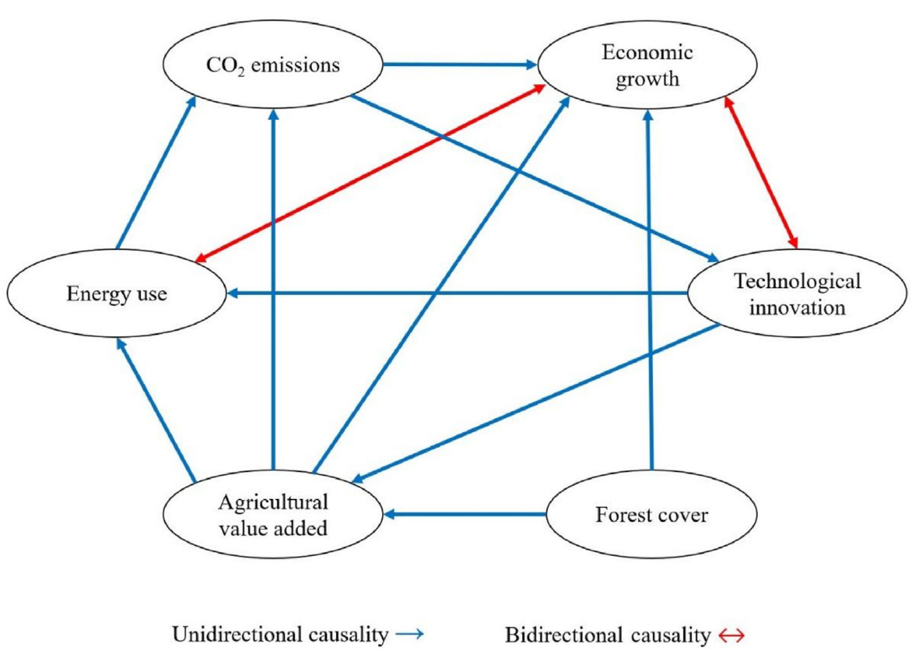


**Fig. 4.** The causal relationship between the variables.

"pollute first, and then treat" strategy and move away from an economic development framework that neglects environmental considerations. The study proposes that government support for markets should be facilitated through the establishment of a robust legislative framework. This framework would aim to create long-term value by reducing pollution and application of modern innovations, ultimately leading to a greener economic model. Possible measures to address the release of $CO_2$ may involve implementing a significant carbon tax, adopting carbon capture and storage technologies, and establishing carbon footprint trading schemes. To achieve regional decoupling, significant modifications are required in unified policies and behavioral patterns, besides the rate of technological advancement. Vietnam's economy relies mainly on the consumption of natural assets afterward in industrial sector instead of the advancement of scientifically rigorous products. The primary goal is for the government to support energy efficiency and reduce resource intensity through research and development in production. This support should prioritize modernization through innovative approaches to satisfy expanding demands while minimalizing the exhaustion of natural resources. Encouraging the implementation of sustainable power supplies is vital for addressing the ecosystem damage accompanying economic extension. Policymakers can promote and foster sustainable power companies and technologies. These measures would encourage the adoption of renewable energy sources and diminish dependence on carbon-intensive conventional energy supplies.

Vietnam is exploring the possibility of shifting from conventional fossil fuels to renewable energies to mitigate emissions. Vietnam has ample solar, hydro, and wind energy resources to fulfill its energy requirements. Vietnam has the potential to build technological assistance networks with other countries and expand its renewable supplies. The government can increase financial assistance to foster the implementation of renewable energies. Vietnam has substantial renewable energy resources, both in terms of potential and current utilization. However, the accompanying higher economic costs impede the development of renewable energy. In an effort to reduce reliance on fossil fuels, Vietnam may implement policies that make renewable energy more affordable for businesses and consumers alike. Additionally, in order to improve the efficiency of energy use, Vietnam should emphasize technological development and raise expenditures on new energy-saving technologies. Concurrently, it can promote innovation for the extraction, conversion, and application of energy. Besides, it is necessary to improve public education efforts in Vietnam concerning energy conservation and efficiency. In Vietnam, as a developing economy, there is a prevailing preference among the public for inexpensive energy options, although they result in amplified emissions. The administration may utilize monetary subsidies, tax breaks, and administration procurements as fiscal measures to encourage the adoption of cleaner energy sources.

The current stage of technological innovation's impact on emission reduction in Vietnam is in its early phase, necessitating more time for significant outcomes to manifest. In order to achieve emission reduction goals and address the correlation between rising emissions and ecological balance, it is critical to pursue the development of new technologies through investigation and the filing of patents. This step is necessary to achieve net-zero emissions. Hybrid powertrains in automobiles reduce fuel consumption while maintaining performance as opposed to conventional vehicles. Installing energy-efficient cooling systems can result in significant cost savings while maintaining comfort levels. The government may provide financial grants to businesses engaged in technological innovation research that specifically targets energy conservation and emission reduction. The Vietnamese government may strengthen its partnership with educational institutions and scientific research organizations to advance high-tech innovation, especially within the realm of eco-friendly technology. Furthermore, the implementation of eco-friendly technology, including technology for waste and recycling management, systems for the storage and management of energy, renewable energies, and the disposal of GHGs, can support the maintenance of a sustainable lifestyle. The adoption of eco-friendly technology in corporate environments is expected to produce desirable results for social, economic, and environmental concerns. Vietnam may determine that advocating for globalization's benefits besides engaging in international assistance to apply advanced technologies is advantageous.

This exploration proposes that representatives in Vietnam should implement efficient plans for better ecological attributes by promoting agricultural yield. There is a need to prioritize the improvement of agricultural output by adopting contemporary agricultural methods, together with crop varieties that are resistant to diseases and have a high yield. The implementation of organic, low-carbon farming practices boosts carbon sequestration while decreasing emissions. The authority's support for renewable energies, particularly solar besides wind power, can improve agricultural output and help mitigate climate change. Renewable energy incentives for agricultural practices can improve global market competitiveness and decrease pollution emissions. Transitioning irrigation methods from fossil fuels to green energy can help lessen emissions. Significant agricultural changes include the promotion of solar-powered irrigation wells, the adoption of organic agricultural practices, the implementation of tunnel agricultural techniques, the transition from outdated tilth to no-till methods, and the reduction of fertilizer usage to mitigate environmental consequences. Contemporary farming methods can improve efficiency; decrease labor needs, boost productivity, and reduce emissions in large-scale farming. In order to achieve sustainable agriculture and reduce pollution, it is crucial to minimize the utilization of fertilizers and pesticides and prioritize environmentally friendly organic agriculture methods. Increasing international collaboration to enhance agricultural investment in Vietnam can help reduce pollutants from the farming area and boost agricultural value added.

The research indicates that policymakers in Vietnam have effectively implemented climate-resilient and ecologically beneficial strategies, with a specific emphasis on cutting emissions via the promotion of forest growth. The Vietnamese government should integrate sustainable forest management into its forestry policy to support sustainable development, including the conservation of environmental quality and the social and economic benefits derived from forests. Collaborating with state administrations to replant trees and rehabilitate degraded forest regions may be crucial for promoting environmental sustainability in Vietnam. The Vietnamese government is contemplating augmenting financial investment to enforce stringent forest regulations. In addition, the authority could explore the creation of planting zones for private forests to encourage private investors to participate in forest development projects. Vietnam and international organizations could cooperate to boost investment in initiatives targeting emission reduction through forest management. Activities like REDD+, as well as the Clean Development Mechanism (CDM), are two established mechanisms and programs. Vietnam can improve its capacity to address climate change by implementing various forest-based mitigation programs. The application of appropriate forestry policies in Vietnam is crucial for achieving net-zero emissions.

### *5.3. Limitations and future research*

The research has delivered significant practical findings for Vietnam. Nevertheless, it is crucial to admit the limitations of the analysis and take them into account for future research. One significant constraint of this assessment is the absence of information on advances in technology plus forest cover outside the data range, which limits the effectiveness of the econometric techniques. Future research should explore other socioeconomic factors that impact environmental quality but were not investigated in this study. These parameters may encompass liberalization in trade, urbanization, FDI, industrialization, globalization, and institutional quality, among others. Additionally, alternative indicators of pollution like particulate matter (PM) or ecological footprints. Future research on the interconnection of environmental pollution indicators in Vietnam could also incorporate additional indicators like land or water pollution. Besides, additional studies could be conducted in the settings of other emerging nations using alternative econometric models like CS-ARDL. Furthermore, future research could utilize sophisticated econometric techniques to contrast the outcomes of several economies with the overall panel results, besides conducting panel approximations. The comparisons may offer valuable insights into the relevant literature, complementing the result of this paper.

## CRediT authorship contribution statement

**Asif Raihan:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Mohammad Ridwan:** Writing – review & editing, Visualization, Software, Methodology, Investigation, Formal analysis, Data curation. **Tapan Sarker:** Writing – review & editing, Supervision, Investigation. **Filiz Guneysu Atasoy:** Investigation, Writing – review & editing. **Grzegorz Zimon:** Investigation, Writing – review & editing. **ABM Mainul Bari:** Writing – review & editing, Visualization, Investigation. **Md Shoaibur Rahman:** Writing – review & editing, Investigation. **Hayat Khan:** Writing – review & editing, Investigation. **Babla Mohajan:** Investigation, Writing – review & editing.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Acknowledgments

The authors gratefully acknowledge the support provided by King Fahd University of Petroleum & Minerals (KFUPM) for facilitating this research.

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