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Renewable Energy Consumption, and Foreign Direct Investment in  
Vietnam: Evidence from non-linear ARDL approach**



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## Nexus between Environmental Quality with Economics Growth, Renewable Energy Consumption, and Foreign Direct Investment in Vietnam: Evidence from non-linear ARDL approach

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### Abstract

**Purpose:** The purpose of this article is to examine the relationship between economic growth and environmental quality in Vietnam.

**Methodology:** The research employed is the non-linear Autoregressive Distributed Lag (NARDL) approach, utilizing time-series data from 1986 to 2022. The strength of NARDL lies in its consideration of both increasing and decreasing trends in independent variables such as Economic Growth, Energy from Renewable Resources and Foreign Direct Investment (FDI) in a non-linear relationship with the dependent variable, CO<sub>2</sub>.

**Findings:** The research findings indicate that overall economic growth is positively associated with an increase in CO<sub>2</sub> emissions, aligning with the Environmental Kuznets Curve (EKC) theory in the first stage of the inverted U-shape. However, the EKC hypothesis is not supported in later stages, as environmental degradation persists despite economic growth. Renewable resources in primary energy have increased from 6% in 1986 to 16% in 2022, while FDI has risen from 0.03% of GDP in 1986 to 4.3% of GDP in 2021, resulting in a reduction in CO<sub>2</sub> emissions. In other words, the Pollution Haven Hypothesis does not hold in Vietnam. With a net-zero CO<sub>2</sub> target by 2050, Vietnam necessitates rapid, short-term changes to neutralize carbon emissions effectively in the long term.

**Unique Contribution to Theory, Practice and Policy:** To simultaneously ensure economic growth while adhering to Vietnam's carbon neutrality objectives, followings solutions are recommended: (1) increasing the proportion of renewable energy sources and reducing fossil fuel dependency; (2) incorporating modern, environmentally friendly technologies in the industrial sector to diminish resource-intensive practices and reduce dependence on fossil fuels; (3) establishing a legal framework and conditions to attract FDI in technology-intensive sectors, thereby mitigating carbon emissions.

**Keywords:** *Zero Carbon target, Environmental Degradation, EKC hypothesis, Renewable Energy*

## 1. INTRODUCTION

Environmental quality is increasingly concerning for countries as economies rely more on resource exploitation, leading to environmental degradation (Begum et al., 2015). The increasing concentration of CO<sub>2</sub> in the atmosphere continues to disrupt the initial carbon balance, adversely impacting the production processes (Xu & Lin, 2018). Economic development contributes to an enhanced quality of life for people. However, in developing countries, the relationship between the environment and economic growth is a trade-off, as economic development has adversely affected environmental quality (G. M. Grossman & A. B. Krueger, 1995). This issue has led to the Environmental Kuznets Curve (EKC) hypothesis. The EKC hypothesis delineates the relationship between per capita income (i.e., economic development) and environmental degradation through an inverted U-shaped curve. In the initial stages of economic development, environmental degradation tends to increase; however, in the later stages of the U-shaped curve, ultimately, the environment improves after reaching a certain level of economic development (Mehmood & Tariq, 2020; Weimin et al., 2022). This study also relies on the Environmental Kuznets Curve (EKC) hypothesis to investigate the environmental quality and the factors influencing it in Vietnam, where technologies are being implemented and energy-efficient practices are employed to reduce CO<sub>2</sub> emissions.

Regarding industrial production in Vietnam, where the industrial sector plays a crucial role, the average annual growth rate reached 7% from 2011 to 2022. The industrial sector constitutes over 35% of Vietnam's GDP (Vietnam General Statistics Office, 2022). However, industrial production contributes to environmental degradation through carbon dioxide emissions. The production process requires the use of energy sources, primarily non-renewable resources, which are extensively utilized in industrial production in developing countries (Wang et al., 2020). Growth-led policies are increasingly focused on industrial production, regardless of the trade-off with the diminishing quality of the environment (Tsauroi, 2018). When the environment is not a priority, low-emission technologies are still being used, as the technologies currently provide better cost efficiency (Lechtenböhmer et al., 2016). Utilizing high technology in industrial production plays a crucial role in reducing reliance on fossil fuels (Zhang et al., 2016); this also serves as a foundation for the Vietnamese government to consider researching and proposing strategies for employing high technology and energy-efficient technologies.

Regarding foreign direct investment (FDI), Vietnam has an open economy to enhance exports and imports. This includes importing capital and technology through the attraction of foreign direct investment. Foreign direct investment brings numerous short-term and long-term benefits to the country (Stiglitz, 2004). Foreign direct investment (FDI) holds a high proportion of the investment capital, contributing to the intensified economic development in Vietnam. In Vietnam, the industrial sector attracts a significant share of foreign direct investment, accounting for approximately 50% of the total FDI. FDI capital tends to concentrate on processing and manufacturing industries. The objective of foreign investors in Vietnam is to leverage advantages such as the abundant labor force, low labor costs, and tax incentives. Foreign direct investment will impact carbon dioxide emissions in both the short and long term (Seker et al., 2015). In some cases, foreign direct investment (FDI) is considered to have a positive impact on the environment

in the long run (Wang & Huang, 2022), Because FDI is associated with the transfer of technology from developed to less developed countries and involves a greater utilization of renewable energy (Paramati et al., 2017) alternatively, countries receiving FDI should require the implementation of clean production processes and adherence to environmental standards (Mahmood et al., 2023).

Energy is becoming a fundamental issue, serving as a crucial input for the economic development process (Abbasi, Shahbaz, et al., 2021). In this context, energy from non-renewable sources, such as fossil fuels, oil, and coal, contributes to the increase in CO<sub>2</sub> emissions (Abbasi & Adedoyin, 2021). As energy consumption rises, it implies an increase in the production process; however, there is a need to transition to the use of renewable energy to contribute to reducing CO<sub>2</sub> emissions both in the short and long term (Szetela et al., 2022) and improve the quality of the environment (Abbasi, Adedoyin, et al., 2021; den Elzen et al., 2016).

Vietnam's goal is to transition to renewable energy successfully, increase the proportion of renewable energy usage, and significantly contribute to achieving the goal of carbon neutrality by 2050. The greenhouse gas emissions are expected to be around 400 million tons by 2030 and reduced to approximately 100 million tons by 2050. The targets of reducing greenhouse gas emissions by 17-26% by 2030 and about 90% by 2050 are ambitious, requiring a long-term perspective on carbon neutrality.

Examining the relationship between environmental quality, resource use, and economic growth is important as Vietnam commits to achieving net-zero emissions by 2050 and aims for sustainable development by increasing the use of renewable resources. The choice between growth and the environment is always a challenge in economic development; therefore, this study aims to (1) Examine the mix of factors such as ERR, and FDI to assess asymmetry, evaluating both increasing and decreasing trends in their effects on CO<sub>2</sub> emissions in the long term using the non-linear ARDL method, which is advantageous compared to studying linear relationships only; (2) Investigate factors that have a significant share in CO<sub>2</sub> emissions, considering Vietnam's commitment to COP26 for carbon neutrality by 2050; (3) Conduct a test for the existence of the Environmental Kuznets Curve (EKC) hypothesis and the Pollution Haven Hypothesis in Vietnam, then provide suggestions in terms of production technology and the utilization of renewable resources based on the study's findings.

## 2. LITERATURE REVIEW

The Kuznets curve was introduced by a Russian economist Simon Kuznets in the 1950s who explored the inverted U-shape curve between income inequality and growth. After his work, the empirical work with the modification to capture the environmental degradation was done by (G. M. Grossman & A. Krueger, 1995), who adopted the similar phenomena of quadratic relationship but between economic growth and environmental degradation. The authors used GDP per capita to measure growth and air pollutants (Sulfur dioxide and Smoke) for measuring environmental degradation. The results showed that a U-shape relationship exists between the two variables.

Further studies on the Kuznets curve hypothesis, as explained by (Lorente & Álvarez-Herranz, 2016) has shown that the Kuznets curve does not stop at the inverted U-shape, but there



is a next stage, when economic growth increases, causing environmental degradation to start increasing again, considered as the Kuznets curve has an N-shape. The stages of the N-shaped Kuznets curve can be explained as follows: in the first stage, economic growth increases due to scale expansion; in the second stage, the environment is protected by advancements in technology. However, in the third stage, as technology becomes outdated and innovation reaches its limits, environmental degradation begins to increase again. (Koilo, 2019; Zhang, 2021). According to study by (Blampied, 2021) has been mentioned the idea of growth comes first, then environmental protection. Because, the benefits of economic growth are important for the prosperity and well-being of the economy and its citizens, it promotes advances in technology, improves health, education and the overall quality of life (Tim Everett, 2010), and growth tends to be linked with improvements in environmental quality (Shafik, 1994).

CO<sub>2</sub> emissions are trending upward in developing countries (Liu et al., 2021), as industrial production increases (Dinda, 2004; Ouyang & Lin, 2015). Most studies consider CO<sub>2</sub> as an indicator of environmental quality (Bekun et al., 2019; Shi et al., 2020). According to the author (Chen et al., 2019) there is a one-way relationship from GDP to CO<sub>2</sub>. However, many other studies indicate a two-way relationship between GDP and CO<sub>2</sub>, which exists in both the short term and the long term (Acheampong, 2018; You et al., 2022).

This study also examines the consumption of renewable resources. Renewable resources play an important role in sustainable economic development, because green technology and eco-technological innovation are developed to minimize the negative effects of pollution (Chiu & Lee, 2020; Shahbaz et al., 2018), economic growth driven by the consumption of renewable energy will reduce CO<sub>2</sub> emissions (Yang et al., 2021).

In developing countries, FDI contributes to local budgets and economic growth. FDI is expected to be accompanied by advanced technology and clean technology to both bring high value to products and protect the environment, as the author (Zhu et al., 2016) pointed out that foreign investment reduces CO<sub>2</sub> in Southeast Asian countries. The pollution haven hypothesis suggests that developing countries are more likely to experience pollution and degradation when they open their economies to foreign investors (Eskeland & Harrison, 2003; Javorcik & Wei, 2003). This is also a way that wealthier countries (with higher incomes) implement stricter environmental protection measures and transfer polluting goods to developing countries (Copeland, 2008). However, currently, developing countries are also implementing stricter environmental regulations in response to the increasing environmental degradation (Acheampong & Opoku, 2023; Opoku et al., 2022)

There are many research methods examining the relationship between CO<sub>2</sub> and factors such as economic growth, FDI, resource consumption, urbanization, tourism, and transportation. These methods use econometric models to analyze both linear and non-linear relationships. Some studies are summarized in Table 1 below:

**Table 1: Synthesis of some studies on the impact of factors on environmental quality**

Determinants	Methodology	Time	Country	Environmental Kuznets curve validation	Authors
GDP, FDI, Urbanization, Energy consumption, Government education expenditures.	Pooled Mean Group Estimator.	1986 – 2017	5 ASEAN developing countries	Existence of EKC	(Tebourbi et al., 2023)
GDP, Renewable energy consumption, Capital account openness.	Second-generation panel data regression models, Quantiles with fixed-effects estimators.	1996 - 2018	ASEAN countries	The inverted-U EKC hypothesis seems to hold true for Singapore.	(Kostakis, 2024)
GDP, Energy consumption, Urbanization.	Auto-Regressive Distributed Lag (ARDL) modeling based on the Pooled Mean Group (PMG) estimator, Common Correlated Effects Pooled Mean Group (CCE - PMG), Fuzzy-set qualitative comparative analysis (fsQCA)	1990 - 2020	Africa countries	Low-income countries reveals a U-shaped relationship	(Simbi et al., 2024)
GDP, Renewable energy consumption	Fuzzy-set qualitative comparative analysis (fsQCA)		The Gulf Cooperation Countries (GCC), and ASEAN countries	No study about EKC	(Naz et al., 2024)
GDP Green supply chain management, Various recycling practices (including bio-waste, municipal waste, and packaging waste). Tourism, Renewable Energy	Linear and nonlinear panel ARDL models	2000 - 2022	EU countries	No study about EKC	(Mohsin et al., 2024)
GDP, renewable energy nonrenewable energy	Two-step GMM estimator	1990 – 2015	Europe and Central Asia countries	Existence of EKC	(Salahodjaev et al., 2022)
GDP, Energy consumption, Urbanization	Fully Modified Ordinary Least Squares (FMOLS), Dynamic Ordinary Least Squares (DOLS)	1990 – 2016	5 ASEAN countries	Existence of EKC	(Mehmood, 2022)
GDP, Energy consumption, Urbanization	Fixed effect, Random effect, Newey West, Generalized least square.	2003 – 2016	5 ASEAN countries	Existence of EKC	(Adeel-Farooq et al., 2023)
GDP, FDI, Real income, Trade openness, Tourism, Renewable energy.	ARDL - PMG, Granger causality	1995–2018	6 ASEAN countries	Existence of EKC	(Pata et al., 2023)

This study uses country-specific data for Vietnam, while most studies use panel data. Using country-specific data is also important, because panel data tend to generalize regression estimates

across many economies, while environmental policies vary from one country to another. Therefore, the relationship between CO2 emissions and energy consumption can be analyzed for a specific country (Blanchard & Perotti, 2002).

### 3. METHODOLOGY

#### Non-Linear Autoregressive Distributed Lag Model

This study uses time-series data, from 1986 to 2022. According to Tabachnick et al. (2013) and Pham et al. (2022), With time-series data (statistics by year), the sample size is determined by the formula  $(n - k) > 20$ , where  $k$  is the number of independent variables in the model, and  $n$  is the number of period (years). In this study, the number of periods is 36 years (from 1986 to 2022), with 4 independent variables. According to the formula, the result is  $(36 - 4) = 32$ , therefore the sample size meets the requirements of this study.

The nonlinear autoregressive distributed lag model is analyzed through multiple steps, progressing from the general model to cointegration testing, evaluating the Error Correction Term (ECT) model, assessing long-term relationships, and conducting an analysis of asymmetric dynamic multiplier graphs. Therefore, this study examines relationships among factors from a simple model and systematically progresses through these analytical stages.

The linear ARDL model as Eq. 1:

$$\ln\text{CO2}_t = \alpha_0 + \sum_{j=1}^p \gamma_j \ln\text{CO2}_{t-j} + \sum_{i=0}^q \alpha_{1,i} \ln\text{GDP}_{t-i} + \sum_{i=0}^q \alpha_{2,i} \ln\text{ERR}_{t-i} + \sum_{i=0}^q \alpha_{3,i} \ln\text{FDI}_{t-i} + \varepsilon_t \quad (\text{Eq. 1})$$

Symbol  $p, q$  represent the optimal lags for each variable in the model. The selection of optimal lags for variables can be performed by relying on AIC (Akaike Information Criterion) or SIC (Schwarz Information Criterion) criteria. In this study, the EViews software is used, and the software automatically selects the optimal lag for each variable  $s$  suggested by Nsor-Ambala and Amewu (2023). The  $\varepsilon_t$  is an IID process with zero mean and constant variance,  $\sigma_\varepsilon^2$ .

The Non-linear ARDL (NARDL) model also introduces an additional asymmetric component, which is absent in the standard ARDL. This study examines the increase and decrease of energy from renewable sources, and foreign direct investment about carbon dioxide emissions. Specifically, in Eq. 1, decompose the independent variable of  $\ln\text{ERR}$  into two sets, denoted by  $\ln\text{ERR}^+$ ,  $\ln\text{ERR}^-$  are partial sum of positive and negative change. Thus, the decomposition series can be expressed as Eq. 2:

$$\ln\text{CO2}_t = \alpha_0 + \alpha_1 \ln\text{GDP}_t + \alpha_2^+ \ln\text{ERR}_t^+ + \alpha_2^- \ln\text{ERR}_t^- + \alpha_3 \ln\text{FDI}_t + \varepsilon_t \quad (\text{Eq. 2})$$

To examine the nature of the increase and decrease in the values of the regressors, the general model of NARDL, Eq. 3.

$$Y_t = \sum_{j=1}^p \gamma_j Y_{t-j} + \sum_{i=0}^q (\alpha_i^+ X_{t-i}^+ + \alpha_i^- X_{t-i}^-) + \varepsilon_t \quad (\text{Eq. 3})$$

In this study, the NARDL model takes the form of Eq. 4:

$$\ln\text{CO2}_t = \sum_{j=1}^p \gamma \ln\text{CO2}_{t-j} + \sum_{i=0}^q \alpha_1 \ln\text{GDP}_{t-i} + \sum_{i=0}^q (\alpha_2^+ \text{ERR}_{t-i}^+ + \alpha_2^- \text{ERR}_{t-i}^-) + \sum_{i=0}^q (\alpha_3 \text{FDI}_{t-i}) + \varepsilon_t \quad (\text{Eq. 4})$$

**Table 2: Description of variables in the dataset**

Variable	Unit measurement	Period	Data source
CO2	Annual CO <sub>2</sub> emissions (tons)	Annual data, from 1986 to 2021	Global Carbon Budget (2022)
GDP	USD per capita, constant 2015, US\$	Annual data, from 1986 to 2022	World Bank Indicators, 2023
ERR	Share of primary energy from renewable sources (%)	Annual data, from 1986 to 2022	Energy Institute Statistical Review of World Energy (2023)
FDI	Foreign direct investment, net inflows (% of GDP)	Annual data, from 1986 to 2021	World Bank Indicators, 2023

Table 3 provides descriptive statistics for the variables used in the study. The variables have different units of measurement; therefore, when implementing procedures for the NARDL model, the values of the variables are transformed using logarithms, as mentioned in the Eq. 1:

**Table 3: Descriptive statistics of variables**

Indicator	CO2 (Million tons per year)	GDP (GDP per Capita, US\$, constant 2015)	ERR (% of primary energy)	FDI (NetFlow FDI, % GDP)
Mean	110.84	1700.84	19.19	4.88
Median	81.90	1474.74	20.06	4.43
Standard Deviation	97.14	930.66	5.19	2.72
Kurtosis	0.23	-0.81	1.18	0.69
Skewness	1.10	0.61	-1.12	0.40
Minimum	17.40	598.92	5.44	0.00
Maximum	341.00	3655.46	26.75	11.94
Observations	36	37	37	36

## 4. RESULTS

### 4.1. Test for Data Stationary

The study utilized the Augmented Dickey-Fuller (ADF) test and Phillips-Perron (PP) test to confirm the stationarity of the variables. The unit root test results (Table 4) indicated that the variables  $\ln\text{CO}_2$ ,  $\ln\text{GDP}$  are stationary at order  $I(1)$ , while the variables  $\ln\text{ERR}$ ,  $\ln\text{FDI}$  are stationary at level  $I(0)$ . This demonstrates that the NARDL method is suitable for determining relationships between these variables.



**Table 4: Unit root tests**

Null Hypothesis: The variable has a unit root

Variable	Model	ADF		PP		Order of stationary
		Level	First Difference	Level	First Difference	
lnCO2	Constant	0.533 <sup>ns</sup>	-4.904 <sup>***</sup>	0.319 <sup>ns</sup>	-5.382 <sup>***</sup>	I(1)
	Trend	-3.994 <sup>**</sup>	-4.930 <sup>***</sup>	-2.981 <sup>ns</sup>	-5.391 <sup>***</sup>	
	None	3.743	-1.514	5.274	-3.808 <sup>***</sup>	
lnGDP	Constant	-1.607	-4.063 <sup>***</sup>	0.300	-4.175 <sup>***</sup>	I(1)
	Trend	-0.922	-4.458 <sup>***</sup>	-3.115	-4.312 <sup>***</sup>	
	None	2.174	-0.123	14.728	0.105	
lnERR	Constant	-3.126 <sup>**</sup>	-4.144 <sup>***</sup>	-3.164 <sup>**</sup>	-4.522 <sup>***</sup>	I(0)
	Trend	-2.881	-4.200 <sup>**</sup>	-2.869	-4.637 <sup>***</sup>	
	None	0.808	-4.055	0.672	-4.405 <sup>***</sup>	
lnFDI	Constant	-4.298 <sup>***</sup>	-8.349 <sup>***</sup>	-11.704 <sup>***</sup>	-8.045 <sup>***</sup>	I(0)
	Trend	-3.833 <sup>**</sup>	-8.638 <sup>***</sup>	-10.753 <sup>***</sup>	-8.328 <sup>***</sup>	
	None	-4.854 <sup>***</sup>	-8.399	-4.062 <sup>***</sup>	-8.098 <sup>***</sup>	

Note: \*\*\*, \*\*, \* at the 1%, 5%, and 10% statistical significance, respectively.

Augmented Dickey-Fuller Unit Root Test (ADF) and Phillips-Perron Unit Root Test (PP)

#### 4.2. Estimation of the long-run relationship

Before delving into the detailed analysis of the long-term relationship, the study evaluated the results of the ARDL model (Table 5) to determine the impact of lnGDP, lnERR<sup>+</sup>, lnERR<sup>-</sup>, lnFDI on lnCO2 emissions. The corresponding optimal lags were identified as (2,2,1,2). The ARDL model is statistically significant at the 1% level. The model indicated that the factors under investigation explain up to 81% of the variation in carbon dioxide emissions. Overall, CO2 emissions are increasing due to economic growth from the previous year (significant at the 1% level). However, CO2 emissions also show a decreasing trend with an increase in renewable energy, and an increase in foreign direct investment (significant at levels of 1%, 5%, and 1% respectively).

**Table 5: The estimation results of the NARDL model****Selected model: ARDL (2,2,1,2)**

Variable	Coefficient	Std. Error	t-Statistic	Prob.
CO2(-1)	-0.8226	0.1864	-4.4122	0.0002
GDP(-1)	1.8272	0.3436	5.3172	0.0000
@CUMDP(RR(-1))	-0.1670	0.0712	-2.3445	0.0285
@CUMDN(RR(-1))	0.1554	0.1267	1.2262	0.2331
FDI(-1)	-0.0063	0.0166	-0.3778	0.7092
D(CO2(-1))	0.1926	0.1530	1.2592	0.2212
D(GDP)	0.4398	0.8249	0.5332	0.5993
D(GDP(-1))	-2.0362	1.1513	-1.7687	0.0908
D(FDI)	0.0840	0.0314	2.6735	0.0139
D(RR)	-0.2880	0.0595	-4.8369	0.0001
D(RR(-1))	-0.1614	0.0760	-2.1240	0.0451
C	2.2545	1.4996	1.5034	0.1470
<b>Model statistics</b>				
R-squared	0.8756			
Adjusted R-squared	0.8134			
F-statistic	14.0731			
Probability (F-statistic)	0.0000			

Before analyzing the long-term relationship, the study conducted the NARDL Bound Test to confirm a long-term relationship between the factors and environmental quality in Vietnam. The results of the NARDL Bound Test in Table 6 show that the calculated F-value is higher than the upper bound value corresponding to a 5% statistical significance level. Therefore, it is possible to reject the null hypothesis (H0) and accept the alternative hypothesis (H1): There exists cointegration among variables in the long run, or other words, there is a long-term relationship between environmental quality (proxied by CO2 emissions) and economic growth, renewable energy and foreign direct investment.

**Table 6: NARDL Bound Test estimation**

Null Hypothesis: No levels relationship

F-statistic	F-bounds test statistics		
	Significance	I(0)	I(1)
6.1016	10%	2.7520	3.9940
	5%	3.3540	4.7740
	1%	4.7680	6.6700

At the same time, examining the asymmetry for the long-term ERR factor, Table 7 shows that there is an asymmetry of ERR in relation to environmental quality (proxy through CO2 variable). Thus, dividing ERR into 2 trends is appropriate for this study.

**Table 7: Coefficient symmetry tests**

Null hypothesis: Coefficient is symmetric

Degrees of freedom (simple tests): F(1,22), Chi-square(1)

Variable	Statistic	Value	Probability
<b>Long-run</b>			
lnERR	F-statistic	6.9952	0.0148
	Chi-square	6.9952	0.0082

After confirming cointegration between factors, i.e., understanding it as having a long-run relationship between variables, in Table 8, the estimation results of the NARDL model show that economic growth has a positive impact on CO2 emissions with statistical significance at the 1% level. This implies that when economic growth, GDP, increases by 1%, CO2 emissions increase by 2.22%.

Meanwhile, increasing energy from renewable sources by 1% results in a 0.2% decrease in CO2 emissions (with statistical significance at the 1% level). A decrease in renewable energy also reduces CO2 emissions, but without statistical significance, which is evident in the dynamic multiplier graph of energy from renewable sources with carbon emissions (Figure 1). The black line represents the partial sum of positive changes in renewable energy, while the orange line represents the partial sum of adverse changes in renewable energy. The figure demonstrates a difference when ERR increases (proxy lnERR+) and ERR (proxy lnERR-) decreases, impacting CO2 emissions. This difference is statistically significant, as confirmed by the red line – the test line showing a significant difference within the 95% confidence interval.

Foreign direct investment (FDI) increasing by 1% results in a 0.7% reduction in CO2 emissions, however, without statistically significant.

**Table 8: Estimation of the long-run relationship NARDL model**

Dependent Variable: LNCO2

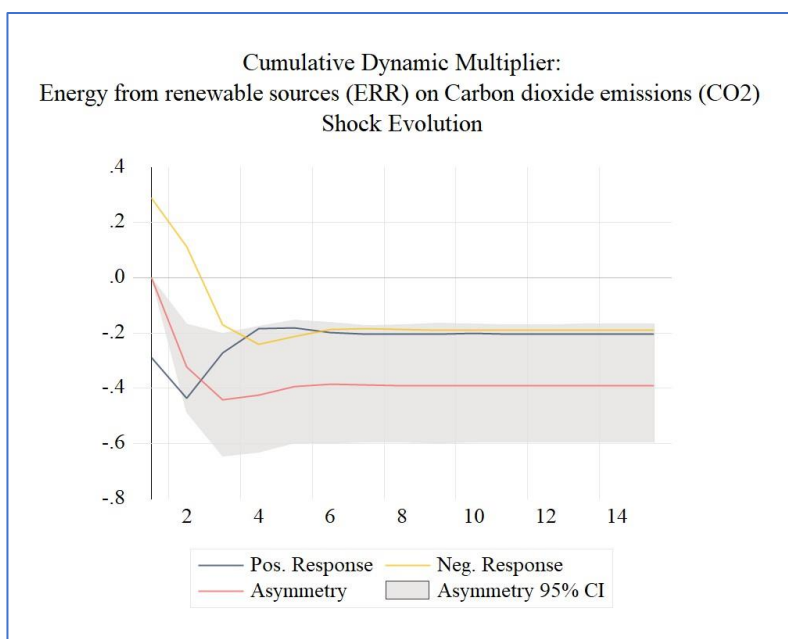
Variable	Coefficient	Std. Error	t-Statistic	Prob.
lnGDP(-1)	2.2211	0.2208	10.0587	0.0000
lnERR <sup>+</sup> (-1)	-0.2030	0.0743	-2.7313	0.0105
lnERR <sup>-</sup> (-1)	0.1888	0.1750	1.0792	0.2891
lnFDI	-0.0076	0.0200	-0.3824	0.7048

Diagnostic tests		
Tests	Prob. F	Prob. Chi-square
Breusch-Godfrey Serial Correlation LM test	0.5119	0.3325
Breusch-Pagan-Godfrey Heteroscedasticity test	0.6913	0.6053

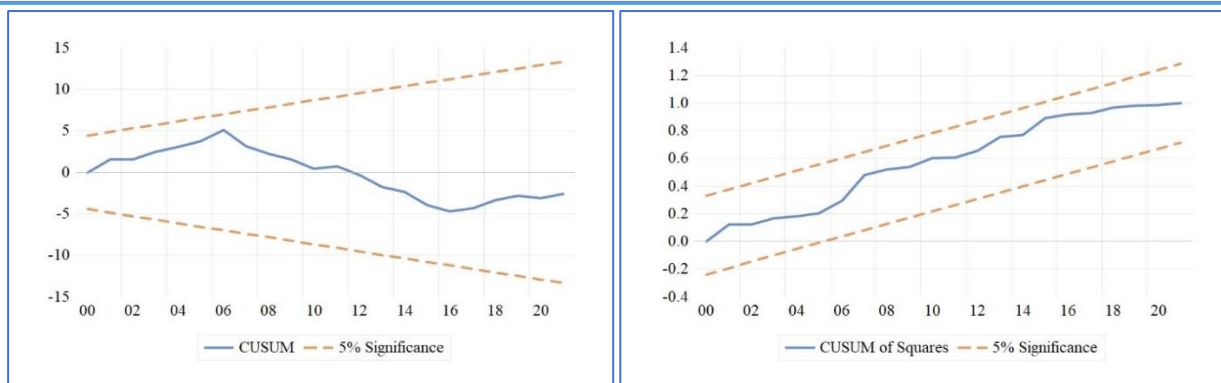
Note: \*\*\*, \*\* and \* show significance at 1, 5 and 10% level respectively.

Breusch-Godfrey LM Serial Correlation test; Breusch-Pagan-Godfrey Heteroscedasticity test; Cumulative Sum (CUSUM) stability test; Cumulative Sum of Square (CUSUM-Sq.) stability test.



**Figure 1: Non-linear ARDL dynamic multiplier effect graphs**

Regarding model testing, Table 8 also presented the diagnostic values of the NARDL model. The statistics indicate the absence of misspecification, serial correlation, and heteroscedasticity. Figure 2 also displays the results for CUSUM and CUSUMQ, indicating that the overall model is stable. The CUSUM line and CUSUMQ line are within the statistically significant region at the 5% level.



**Figure 2: Non-linear ARDL CUSUM and CUSUMSQ graphs**

### 4.3. Error correction model

The results of the NARDL Bound Test confirm the existence of long-run cointegration among the factors. However, to examine the relationship from the short run to the long run, the Error Correction Term (ECT) model with a parameter (CointEq(-1) = -0.8226) (Table 9) has a negative and statistically significant value at the 1% level. This indicates the presence of a long-run relationship among the factors. The relationship will converge, and growth paths will reach long-run equilibrium (or steady-state in the long run). During the process of reaching the steady-state path, the amount of CO2 will be restrained, while economic development continues, i.e., environmental quality is improved with increased economic growth.

**Table 9: Error Correction Model**

Variable	Coefficient	Std. Error	t-statistic	Prob.
COINTEQ*	-0.8226	0.1370	-6.0046	0.0000
D(CO2(-1))	0.1926	0.1327	1.4514	0.1586
D(GDP)	0.4398	0.6526	0.6739	0.5063
D(GDP(-1))	-2.0362	0.8542	-2.3838	0.0247
D(RR)	-0.2880	0.0434	-6.6416	0.0000
D(RR(-1))	-0.1614	0.0614	-2.6276	0.0142
D(FDI)	0.0840	0.0185	4.5338	0.0001
C	2.2545	0.3694	6.1037	0.0000
<b>Model statistics</b>				
R-squared	0.8756			
Adjusted R-squared	0.8421			
F-statistic	26.1357			
Probability (F-statistic)	0.0000			

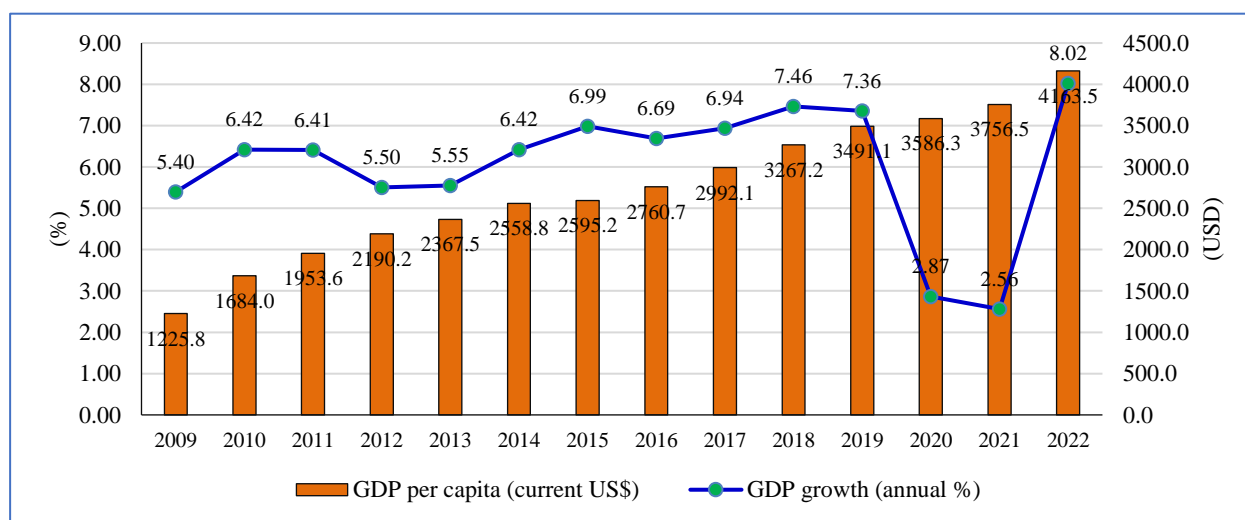
Note: Δ is the difference operator

## 5. DISCUSSION

In 2022, Vietnam's economic growth reached its highest level in the 10 years from 2011 to 2022, as the economy rebounded from the impacts of the COVID-19 pandemic. The GDP growth rate was 8.02%, with the industrial and construction sectors contributing significantly at 7.78%, accounting for approximately 38% of the GDP. Despite global economic uncertainties and challenges, the growth in most countries and regions indicated instability. Vietnam's economic

growth was highly praised, demonstrating the effectiveness of the government's efforts to support economic recovery.

As shown in Figure 3, the GDP scale continues to expand, reaching USD 408.8 billion in 2022 at current prices, compared to USD 195.6 billion in 2012. This doubling of GDP over the past decade translates to a per capita GDP of nearly \$4,200 in 2022. However, entering 2023, Vietnam's economy is facing various difficulties. According to the Asian Development Outlook report (September 2023), Vietnam's economic growth is projected to slow to 5.8% in 2023 and 6.0% in 2024<sup>1</sup>.



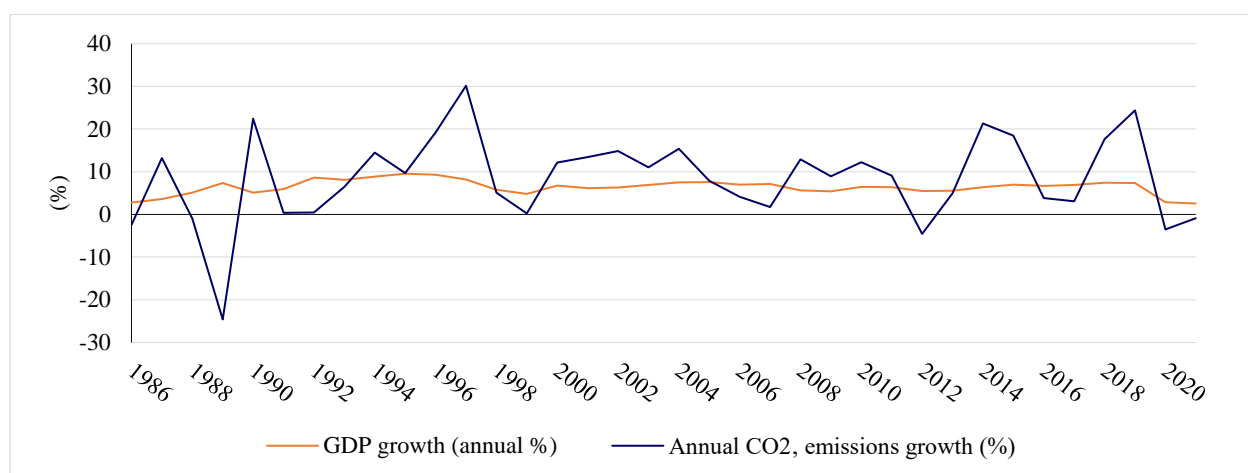
**Figure 3: Economic growth and per capita GDP in Vietnam from 2009 to 2022**

Returning to the NARDL model estimation results, economic GDP growth has a positive relationship with CO<sub>2</sub> emissions. In other words, Vietnam faces environmental degradation as per capita income increases in the short and long term. Figure 4 illustrates that the growth rate of CO<sub>2</sub> follows the growth rate of GDP per capita; however, the growth rate of CO<sub>2</sub> emissions is higher than the growth rate of GDP. This result aligns with previous studies conducted in Vietnam by [Shahbaz et al. \(2019\)](#) and [Al-Mulali et al. \(2015\)](#), finding that the Environmental Kuznets Curve (EKC) hypothesis cannot be achieved at later stages, as CO<sub>2</sub> levels continue to rise despite an increase in per capita income. The positive relationship in the long run is also consistent with the findings of [\(Binh, 2011\)](#). A study by [\(Vo et al., 2019\)](#) also indicated that some countries in the Southeast Asian region, such as the Philippines, do not reveal the Environmental Kuznets Curve (EKC) hypothesis in the long-run relationship between economic growth and environmental quality. In contrast, in Thailand, research results have shown the Environmental Kuznets Curve (EKC) [\(Chng, 2019\)](#). However, some low-income and low-middle-income countries in South Asia, such as Nepal, Bangladesh, and India, still follow an inverted U-shape trend according to a study by [\(Syed Muhammad Faraz et al., 2022\)](#). The SAARC countries (Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, and Sri Lanka) exhibit a long-run relationship where economic growth contributes to environmental degradation, as indicated by a study by [\(Rani et al.,](#)

<sup>1</sup> Vietnamese economy remains resilient despite weak external environment: ADB. <https://link.gov.vn/dmoQVQex>



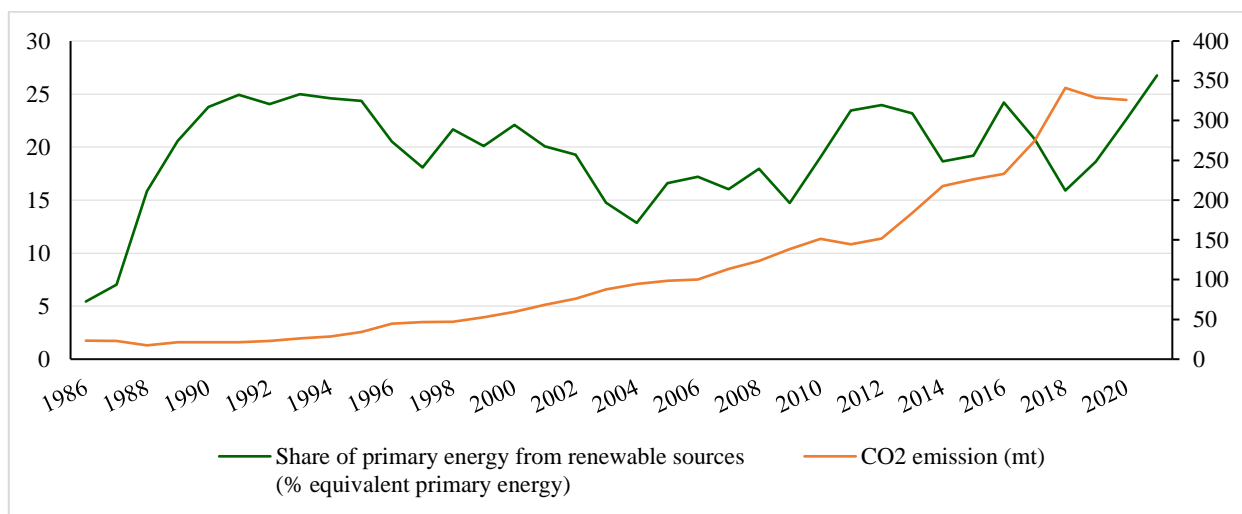
2023). A recent study in Turkey has supported the inverted U-shape relationship according to the Environmental Kuznets Curve (EKC), where energy intensity is identified as a source causing a decrease in environmental quality (Shokoohi et al., 2022). Therefore, in this study, the findings imply that the Vietnamese economy, like other middle-income countries, exploits resources and energy sources, leading to higher CO<sub>2</sub> emissions (Linh & Lin, 2014). Another reason is that Vietnam is focusing on developing the industrial sector, a cause that aligns with previous research by (Shahbaz et al., 2019), as the industry consumes a significant amount of fossil energy, leading to environmental degradation.



**Figure 4: GDP growth and CO<sub>2</sub> emissions growth in Vietnam from 1986 to 2022**

The results have demonstrated that energy intensity from non-renewable resources negatively impacts CO<sub>2</sub> emissions in the long run, and using renewable energy positively affects environmental quality (Awan et al., 2022). Real-world experiments during the COVID-19 pandemic, when oil demand decreased, showed an improvement in environmental quality, with reductions in CO<sub>2</sub> emissions during lockdowns, highlighting the relationship between the energy sector and CO<sub>2</sub> emissions (Ope Olabiwonnu et al., 2022). The study conducted across 107 countries by (Abbasi et al., 2023) indicates that nuclear energy and renewable energy follow the Environmental Kuznets Curve (EKC) hypothesis with an inverted N-shape, leading to pollution reduction, while non-renewable energy enhances pollution. Renewable energy consumption in developed countries like the United States reduces CO<sub>2</sub> emissions at the lowest to medium and the highest quantiles (Raggad, 2023). However, in OPEC countries, renewable energy has an insignificant impact on carbon intensity. Instead, technological innovation, creativity, and energy-efficient measures are employed to control carbon intensity (Aziz et al., 2023). Renewable energy consumption, environmental taxes, and economic growth are longitudinally linked to CO<sub>2</sub> emissions. Eco-friendly innovations also reduce the use of non-renewable energy sources (Ameer et al., 2023). In developed European countries, GDP per capita and CO<sub>2</sub> emissions exhibit a relationship following the Environmental Kuznets Curve (EKC) hypothesis. The increased use of renewable energy sources, especially solar, wind, and bioenergy, reduces CO<sub>2</sub> emissions. The study emphasizes the utilization of advanced technologies (J.-h. Wang et al., 2022). Alternative energy sources to fossil fuels and energy efficiency improvements can reduce pollution (Farhana et al., 2022). The relationship between energy, GDP, and CO<sub>2</sub> always co-occurs, and renewable

energy reduces CO<sub>2</sub> emissions in countries in sub-Saharan Africa (Ebhota & Tabakov, 2021). Research results on renewable energy consumption in Vietnam also indicate a negative effect on greenhouse gas emissions, suggesting that renewable energy could reduce greenhouse gas emissions (Nguyen et al., 2022). Thus, the findings of this study align with research in other countries and in Vietnam, affirming that renewable energy positively impacts environmental quality. However, in Figure 5, it is shown that CO<sub>2</sub> emissions increase at a faster rate than renewable energy consumption, supporting the idea that, in addition to increasing the use of renewable energy, it is crucial to use energy efficiently in industrial production, research, and technology innovation to create environmentally friendly products.

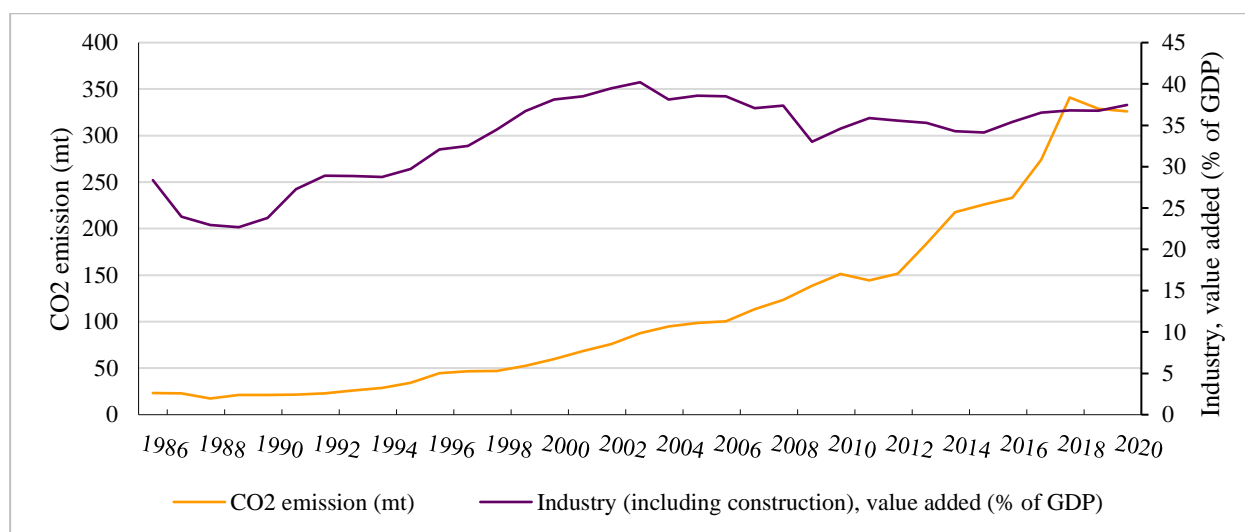


**Figure 5: Share of primary energy from renewable sources and CO<sub>2</sub> emissions in Vietnam from 1986 to 2022**

In Vietnam, thermal power plants using coal and gas-fired thermal power plants are significant contributors to greenhouse gas emissions (Roy et al., 2021). Other industries, such as cement, must compromise by adopting carbonation technologies to reduce CO<sub>2</sub> emissions, which may impact cement plant profits (Proaño et al., 2020). This study aligns with the findings of (Mahmood et al., 2020), which assert that increasing industrialization has a more significant effect on CO<sub>2</sub> emissions than reducing industrialization; however, the authors also highlight that technological progress can still have adverse effects on the environment. Recent studies have introduced a novel approach, utilizing the concept of lean manufacturing to optimize resource utilization and minimize waste, where companies strive to improve output efficiency by adjusting production parameters (Singh et al., 2021). Additionally, industries such as iron and cement manufacturing in Vietnam need dedicated production and environmental processing areas to mitigate their environmental impact (Cravioto et al., 2021). Therefore, the results of this study, in line with previous research, affirm that industrial production in Vietnam contributes to environmental degradation. This supports the idea that to enhance environmental conditions, industries should establish separate production zones and improve energy efficiency.

In terms of industrial production, in Vietnam in 2022, there are four primary industries, with the processing and manufacturing industry accounting for the most significant proportion of GDP (24.7%), followed by electricity production and distribution (3.99%), mining industry

(2.82%), and finally water supply (0.49%). Industrial production continues to grow relatively, with the average industrial value-added increasing by 7% per year from 2011 to 2022, contributing 38% to GDP in 2023 (Vietnam General Statistics Office, 2022). The industrial and CO<sub>2</sub> emission growth rates are high, as depicted in Figure 6. Previous research by H. Zhang et al. (2022) showed that the iron and steel production industry contributed significantly to CO<sub>2</sub> emissions in the studied areas in China, and the flow from production to energy had a statistically significant impact on CO<sub>2</sub> emissions. Similarly, within the steel production sector, research by (S. Zhang et al., 2022) demonstrated that the steel output, resource-saving, and energy-efficient practices determined the amount of CO<sub>2</sub> emissions. While some countries participating in global value chains benefit from reducing pollution emissions in their own countries, developing countries face challenges in dealing with increased pressure to reduce carbon emissions (S. Wang et al., 2022).



**Figure 6: Share of industry of GDP and CO<sub>2</sub> emissions in Vietnam from 1986 to 2022**

"Economic growth is positively correlated with the annual increase in Foreign Direct Investment (FDI) in Vietnam. FDI capital holds a significant share in the overall investment in the entire economy. The rise in FDI has expanded the production scale in various economic sectors, thereby creating conditions to promote economic growth. In a study by (Firoj et al., 2023), the author revealed a long-term relationship following the Environmental Kuznets Curve (EKC). However, it did not provide evidence that FDI contributes to environmental pollution in Bangladesh. The sensitivity of FDI to the environment is high (Chishti, 2023). The relationship between FDI and economic growth is bidirectional, and low-middle-income countries support the pollution haven hypothesis (Yin et al., 2021).

The study conducted across 15 OECD countries supports the pollution haven hypothesis. Results from various sectors, including mining and manufacturing from Foreign Direct Investment (FDI) lead to an increase in CO<sub>2</sub> emissions (Marques & Caetano, 2022); similar findings are reported by (Esmaeili et al., 2023; Liu et al., 2022), indicating that FDI can negatively impact environmental quality. However, the findings of this study show a positive impact of FDI on environmental quality in Vietnam, contrary to (Tran et al., 2023), who conducted a study in Vietnam and found that an increase in Foreign Direct Investment (FDI) leads to an increase in

greenhouse gas emissions in the country. This emphasizes the need for FDI inflows to actively engage in green technology transfer, fulfill social responsibilities, and build and enhance awareness of a green economy among workers and consumers.

## 6. CONCLUSIONS

By employing the non-linear Autoregressive Distributed Lag (ARDL) method, this paper investigates long-term relationships between various regressors, including economic growth, the share of renewable energy usage, and foreign direct investment, with environmental degradation (measured through carbon dioxide emissions). One of the main reasons for conducting this study is to examine both increasing and decreasing (asymmetric) trends of renewable energy regressor in the context of the rising carbon dioxide emissions in Vietnam. The study results indicate a cointegrated relationship among the factors, wherein Vietnam's economic growth does not follow the Environmental Kuznets Curve (EKC) hypothesis and the relationship between FDI and environmental quality is not statistically significant. This implies that high economic growth still requires high energy consumption and produces substantial greenhouse gas emissions. The study also reveals that an increase in the use of renewable energy and foreign direct investment has a positive impact, reducing carbon dioxide emissions in the long run.

## 7. RECOMMENDATIONS

To simultaneously ensure economic growth while adhering to Vietnam's carbon neutrality objectives, followings solutions are recommended:

Firstly, the key strategies involve decreasing reliance on fossil fuels, increasing the utilization of renewable energy, and continuing the upward trend in harnessing energy from wind and solar sources. Moreover, as outlined in Vietnam's energy plan, the gradual reduction of thermal power in the energy supply has gained approval.

Secondly, modern technology may require some industries to sacrifice profits to protect the environment, particularly in the industrial sector. Renewable energy, modern technology, and efficient energy use are the pathways for development to enhance environmental quality while ensuring both short-term and long-term economic growth. This aligns with the commitment made by Vietnam at COP26 to achieve carbon neutrality by 2050.

Thirdly, there is a need to focus on less resource-intensive industries and attract environmentally friendly technologies. For industries with high CO<sub>2</sub> emissions, strategic planning must allocate them to specific zones. Applying a circular economy model and using energy efficiently from fossil fuels are recommended for FDI in industrial sectors. The industrial production sector needs to transition technology, gradually prioritizing technology-intensive sectors over resource-intensive ones.

### Ethical Approval

This article contains no studies with human participants or animals performed by authors.

### Data Availability Statement

The data supporting this study's findings are available from the first author upon reasonable request.

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This research received no external funding.

### Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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