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Nexus between CO_2 Emissions and Economic Growth, Industrial Production, and Foreign Direct Investment in Vietnam: Symmetric ARDL Approach

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Abstract

Vietnam's economy has been developing strongly in recent years; however, it is necessary to examine the impact of its economic activities on environmental quality. This study aims to evaluate the relationship between CO_2 emissions and economic growth, industrial production, and foreign direct investment (FDI) in Vietnam. The ARDL estimation was used to process the dataset from World Bank. Results showed that economic growth, industrial production, and FDI have an impact on CO_2 emissions in the long run in Vietnam. Granger Causality test also indicated that there is a causal relationship between economic growth, industrial production, and CO_2 emissions in Vietnam from 1990 to 2018, at 5% statistical significance level. Proposed solutions to reduce CO_2 emissions but still promote economic growth toward the green growth orientation and zero carbon target attainment are as follows: 1) reduce the use of fossil energy in industrial manufacturing and replace it by renewable energy sources; 2) use modern technology for all production sectors in economy; and 3) develop a legal framework for FDI projects selection and choose foreign investors with modern and low carbon emission technology.

Keywords

Economic Growth, CO_2 Emission, FDI, ARDL, Environmental Kuznets Curve (EKC)

1. Introduction

In recent years, the economy of Vietnam has been experiencing fast growth. Its GDP per capita increased from 1562 US$ in 2010 to 3561 US$ in 2020, with its government targeting to reach 7500 USD per capita by 2030 [1].

With a greener development goal, Vietnam has committed to achieving a net zero carbon target by 2050 [2]. Net zero means cutting greenhouse gas emissions to near zero. The remaining emissions must also be reabsorbed into the atmosphere, oceans, and forests. With this commitment, Vietnam follows a green economy or a low-carbon economy, and reducing CO_2 emissions has become a vital component of its economic activities. By 2050, total carbon emissions will be only about 185 million tons of CO_2 equivalent (CO_2eq); however, total net greenhouse gas emissions in 2016 is 316.7 million tons of CO_2eq, of which the energy sector accounts for the highest share of emissions [3].

Since 1991, Vietnam has been the target destination of foreign investors which increased its FDI capital gradually over the years. Notably, when Vietnam joined the World Trade Organization in 2007, the country's registered FDI inflows increased. FDI capital increase expands the production scale of economic sectors, thereby creating conditions to promote economic growth. FDI sector percentage in GDP tends to increase gradually. In 2019, FDI contributed 20.35% to GDP growth. This result shows that FDI sector is increasingly making important direct contributions to economic growth [4].

While industrial production and FDI capital increase have contributed to economic growth, the same has also led to adverse environmental incidents due to discharge activities from FDI enterprises in recent years. This highlights that FDI activities also have negative impacts on the environment in Vietnam. In order to continue economic growth, industrialization, attract foreign direct investment, and fulfill its commitment to reduce emissions, Vietnam needs to consider this relationship in the short term and long term.

Economic growth is the increase in the value of an economy over a given period. This value is measured by annual GDP or GDP per capita [5] [6]. This study used GDP per capita as the main measurement for economic growth. There have been many previous studies that investigated the relationship between economic growth and CO_2 emissions. The study by Morelli and Mele [7] on energy consumption, CO_2, and economic growth in Vietnam showed this relationship to be statistically significant even in the short run. The study of El Menyari [8] on the effects of tourism, electricity consumption, and economic growth on CO_2 emissions in several countries in North Africa has shown this relationship according to Environmental Kuznets Curve hypothesis, *i.e.* economic growth also emits more CO_2 and power consumption has a positive effect on CO_2. The study of Ru, Shindell [9] also confirmed that CO_2, especially CO_2 from coal used for four sectors such as power, industry, residential, and transportation all affect economic growth in long run. A study on selected provinces in China found that low-emission electricity production increased GDP per capita and reduced CO_2 emissions, towards low-carbon economic development [10]. In OECD countries, results are also consistent with Environmental Kuznets Curve hypothesis that CO_2 emissions and economic growth have a bi-directional relationship, and suggest that international cooperation is needed to reduce CO_2 emissions [11]. Authors [12] [13] [14] also showed a positive relationship between economic growth and CO_2 emission. To reduce CO_2 emissions, Asian countries need green investment, technology innovations and environmental protection tax [15]. The Environmental Kuznets Curve hypothesis is validated in the given period time and indicated inverted U-shaped linkages between economic growth *and* CO_2 emission [16] [17], while Chebbi, Olarreaga [18] found a negative relationship between economic growth and CO_2.

Overall, studies have confirmed that economic growth and CO_2 have a relationship following the Environmental Kuznets Curve hypothesis which shows the trade-off of environmental deterioration and GDP growth. This study examined the existence of a trade-off between environmental quality and economic growth, testing EKC in the case of Vietnam.

With regard to foreign direct investment, FDI enterprises are investing in developing countries. The Pollution Haven Hypothesis argues that firms will seek to avoid cost of stringent environmental regulations and avoid high energy prices by locating production in countries where there are less stringent environmental regulations [16]. Other studies have also shown a positive relationship between population growth, FDI inflow, trade, and CO_2 emission. However, the relationship between FDI and CO_2 usually occurs in short term. In the long term, FDI inflow will reduce CO_2 emissions [19] [20] [21] [22] [23]. FDI inflows are considered an important factor in economic growth in Asian countries [24], similar to some other Middle Eastern countries, where there is a bi-directional relationship between economic growth and FDI and energy consumption: energy consumption generates CO_2 emissions [25]. Studies show that FDI has a positive effect on economic growth and this is a two-way relationship [21] [26] [27] [28], these studies also confirm the Pollution Haven Hypothesis, and recommend that countries should carefully choose foreign investors.

The abovementioned studies have shown that FDI has an important role in economic growth in developing countries. FDI inflow increases CO_2 emissions in the short term. In the long run, countries have a choice among different technologies and foreign investors Hence, CO_2 emissions will be decreased even though FDI inflows increase. This study in Vietnam examined the extent to which FDI affects economic growth, domestic industrial production, and CO_2 emissions. Studies have shown a two-way relationship between CO_2 emissions and industrialization [29] [30]. Studies also reconfirmed the Environmental Kuznets Curve between industrial development and CO_2 emissions in both short and long term, in addition, CO_2 emissions are also affected by population density and trade [31] [32] [33] [34]. They also showed that the economy is moving toward the use of clean, renewable energy [33] [35]. Previous studies have shown the important role of industrialization in economic growth, but there must be a trade-off between industrialization and environmental deterioration because of increased CO_2 emissions.

Regarding methodology, previous studies, when studying short-and long-term relationships between economic growth and CO_2 emission, FDI inflow, industrialization, energy, population density, trade and other factors, commonly used ARDL estimation and Granger Causality analysis [36] [37] while some studies used VAR (Vector Auto Regression Model) [38] or cointegration test and vector error-correction model (VECM) [39] [40].

The synthesis of previous studies shows that, in the short term, economic growth must be traded off with an increase in CO_2 emissions, the lack of choice in foreign investors in the short term which leads to acceptance of outdated technology. However, in the long term, development to a certain extent, economic growth, and FDI have a positive impact on the environment. This can come from increasing technology content and using clean energy, to achieve a zero CO_2 target. This study re-examined the above relationships in Vietnam, assessed the trade-off between economic growth and environmental degradation in Vietnam in the last 30 years. Relationship analysis between economic growth and CO_2 emissions based on the Environmental Kuznets Curve hypothesis (EKC), FDI inflow analysis based on "pollution haven hypothesis", along with analysis of the industrialization process in Vietnam, was conducted to form the recommended solutions toward a green economy.

2. Methodology

2.1. Data

The study used time-series data collected from World Bank data, specifically the World Development Indicators (WDI). Economic growth is represented by gross domestic product per capita (Vietnam's real GDP constant in 2015, US$) from 1990 to 2018. Industrial production is represented by value added (% GDP), value added in constant 2015 US$, from 1990 to 2018. Foreign direct investment is represented by net investment flows into Vietnam as a percentage of GDP (% of GDP). Environmental degradation is reflected in CO_2 emissions, corresponding to the amount of CO_2 emitted per capita (metric tons per capita) from 1990 to 2018. The WDI dataset 2021 updates CO_2 emissions data to 2018, so to unify other variables, the study takes data up to 2018. According to Tabachnick, Fidell [41] and Pham Hong, Dai [42], in time series data (statistics by year), to determine sample size by using the formula $(n - k) > 20$, where k is independent variables in the model, n is the number of periods. This study used a period of 28 years (between 1990 and 2018) with 3 independent variables, so that sample size was determined to be $(28 - 3) = 25$. Hence, the data meets the sample size requirements for this study.

2.2. Research Model

1) Basis model

The study is based on the Environmental Kuznets Curve hypothesis, trade-off relationship between environmental degradation and economic growth. It is understood as the relationship between CO_2 emissions (environment degradation) and income per capita. The level of environmental degradation is expressed by CO_2 emissions per capita. Economic growth is represented by GDP per capita. Moreover, this study also considers value-added of industry sector contributing to GDP and inflow foreign direct investment in Vietnam.

Relationship is expressed through a simple model as follows:

$$\text{CO2}_t = \alpha_0 + \alpha_1 \text{GDP}_t + \alpha_2 \text{INDUSTRY}_t + \alpha_3 \text{FDI}_t + \varepsilon_t \quad (1)$$

where, CO2_t is CO_2 emissions per capita over years (tons per capita)

GDP_t is gross domestic product per capita over years (constant 2015, US$);

INDUSTRY_t is share of industry sector in GDP over years (% GDP);

FDI_t is rate foreign direct investment in GDP over years (% GDP).

Variables CO2_t, GDP_t, INDUSTRY_t, FDI_t measured in different unit measurements, specifically CO2_t measured in tons.kt, GDP_t measured in currency, INDUSTRY_t and FDI_t measured in percentage units, so variables are calculated as logarithm and Equation (1) is converted to estimated form as follows:

$$\ln \text{CO2}_t = \gamma_1 + \gamma_2 \ln \text{GDP}_t + \gamma_3 \ln \text{INDUSTRY}_t + \gamma_4 \ln \text{FDI}_t + \varepsilon_t \quad (2)$$

2) Empirical model

Autoregressive (AR) model, in autoregressive model, independent variables are all lagged dependent variables. There is no other independent variable.

Distributed lag (DL), independent variable appears more than 1 variable, with different lags. It is called DL because the influence of independent variable is spread out or distributed across-several time periods.

The Autoregressive Distributed Lag (ARDL) model in time series data analysis consists of two components: 1) Autoregressive component (AR—Autoregressive) —dependent variable is related to its value in previous period (lag); 2) Delayed component (DL—Distributed lag) —independent variable affects the dependent variable with different lags.

The ARDL model as follow:

$$\begin{aligned}\ln \text{CO2}_t = \alpha_0 &+ \sum\nolimits_{m=1}^{p_1} \alpha_{1,m} \ln \text{CO2}_{t-m} + \sum\nolimits_{i=0}^{p_2} \alpha_{2,i} \ln \text{GDP}_{t-i} \\ &+ \sum\nolimits_{j=0}^{p_3} \alpha_{3,j} \ln \text{INDUSTRY}_{t-j} + \sum\nolimits_{k=0}^{p_4} \alpha_{4,k} \ln \text{FDI}_{t-k} + \varepsilon_t\end{aligned} \quad (3)$$

Symbol (p_1, p_2, p_3, p_4) are optimal lags of each variable in the model, selection of optimal lags for variables can be done by relying on AIC or SIC criteria.

This study will analyze cointegration among variables to find out whether there is a long-run relationship (or steady state), and consider how the relationship is achieved, since in short run it can be disequilibrium.

2.3. Procedures for Data Analysis by ARDL

2.3.1. Advantages of ARDL

One requirement when regressing time series data is stationarity. In the model, there is a stationary variable at level, I(0), and stationary variable at first difference, I(1), cointegration test methods such as Engle and Granger [43] based on the 2-stage residual and the maximum likelihood method of Johansen [44], can lead to bias results about interactions between variables in long run. Regarding this problem, Autoregressive Distributed Lag (ARDL) method proposed by Pesaran, Shin [45] gives unbiased estimation results even variables' stationary are at both levels I(0) and I(1) [46]. The Johansen procedures will be applied, when all variables are stationary at level I(0). Therefore, one ARDL advantage is that it is not necessary to look at the variables' stationary [47], when all variables are stationary at I(1) or variables are stationary at both I(0) and I(1), the ARDL model is an optimal choice.

2.3.2. Unit Root Test

Unit root test is to check variables' stationarity. This step is performed on variables $\ln CO2_t$, $\ln GDP_t$, $\ln INDUSTRY_t$, $\ln FDI_t$ to check if variables are stationary at level, I(0), or stationary at first difference, I(1). Although, ARDL method does not require checking the data's stationarity. However, without test for stationarity, the study will sometimes give false regression result, when data is not stationary or stationary at second difference.

This type of study can also use Augmented Dickey-Fuller (ADF) root test by Dickey and Fuller [48] or Phillips Perron (PP) root test by Phillips and Perron [49] to test stationary. Acceptance or rejection the null hypothesis (H0): data is non-stationary, depends on the t-test. If the t-test is statistically significant, then hypothesis H0 is rejected. In this study, an Augmented Dickey-Fuller root test (ADF) is used.

2.3.3. ARDL Bound Test

Cointegration test is an important step in ARDL estimation process. This step is taken to explain long-run relationship between variables. Studies in economic field can use Johansen cointegration method in estimating long-run relationship between variables because this is considered the best way when dealing with variables that are stationary at level, I(0). However, recent studies have introduced bound test in ARDL as an alternative and have more benefits than Johansen cointegration method.

ARDL model is a more statistically significant approach to test the cointegration between variables when study data size is small, while Johansen's cointegration technique requires a larger number of samples to achieve reliability [50] [51]. This study, time-series data includes 29 observations, so the number of observations is small, so it is reasonable to apply ARDL method.

The ARDL model has two main steps in estimation, namely: cointegration test to determine long-run relationship and error correction model (ECM) to test the adjustment rate to equilibrium. According to Pesaran [50], bound test in ARDL procedure, to determine the existence or non-existence a long-run cointegration relationship between variables.

$$\begin{aligned}\ln CO2_t &= \alpha_0 + \sum_{m=1}^{p_1}\alpha_{1,m}\Delta\ln CO_{t-m} + \sum_{i=0}^{p_2}\alpha_{2,i}\Delta\ln GDP_{t-i} \\ &+ \sum_{j=0}^{p_3}\alpha_{3,j}\Delta\ln INDUSTRY_{t-j} + \sum_{k=0}^{p_4}\alpha_{4,k}\Delta\ln FDI_{t-k} \\ &+ \varphi_1\ln CO_{t-1} + \varphi_2\ln GDP_{t-1} + \varphi_3\ln INDUSTRY_{t-1} \\ &+ \varphi_4\ln FDI_{t-1} + \varepsilon_t\end{aligned} \tag{4}$$

The hypothesis for the test is:

H0: $\varphi_1 = \varphi_2 = \varphi_3 = \varphi_4 = 0$: there is no cointegration relationship between variables, that is, there is no long-run relationship between variables.

H1: $\varphi_1 \neq \varphi_2 \neq \varphi_3 \neq \varphi_4 \neq 0$: there exists a cointegration relationship between variables, that is, there exists a long-run relationship between variables.

To test the hypothesis H0, it is necessary to compare calculated value F-statistic with two bound value (lower bound, I(0) and upper bound, I(1)): If the F-computation value is greater than the upper bound value, then null hypothesis H(0) is rejected. The conclusion exists that there is a cointegration relationship between variables.

If F-computation value is less than lower bound value, then the hypothesis H0 is accepted. The conclusion is that there is no cointegration relationship in long run. If F-computation value lies between two bound values, no conclusion can be drawn.

The long run equilibrium equation is written as:

$$\ln CO2_t = \gamma_1 + \gamma_2\ln GDP_t + \gamma_3\ln INDUSTRY_t + \gamma_4\ln FDI_t + \varepsilon_t \tag{5}$$

where, long-run coefficients $\gamma_0, \gamma_1, \gamma_2, \gamma_3$ is defined as follows:

$$\gamma_1 = \frac{\alpha_0}{1-\sum_{m=1}^{p_1}\alpha_{1,m}};\quad \gamma_2 = \frac{\sum_{i=0}^{p_2}\alpha_{2,i}}{1-\sum_{m=1}^{p_1}\alpha_{1,m}};\quad \gamma_3 = \frac{\sum_{j=0}^{p_3}\alpha_{3,j}}{1-\sum_{m=1}^{p_1}\alpha_{1,m}};\quad \gamma_4 = \frac{\sum_{k=0}^{p_4}\alpha_{4,k}}{1-\sum_{m=1}^{p_1}\alpha_{1,m}}$$

2.3.4. Error Correction Model

Error correction model (ECM) will be used to identify variables with cointegration [52] [53].

To analyze trend for change on the long-term equilibrium (or steady state), this study uses error correction model.

$$\begin{aligned}\Delta\ln CO2_t &= \alpha_0 + \sum_{m=1}^{p_1}\alpha_{1,m}\Delta\ln CO2_{t-m} + \sum_{i=0}^{p_2}\alpha_{2,i}\Delta\ln GDP_{t-i} \\ &+ \sum_{j=0}^{p_3}\alpha_{3,j}\Delta\ln INDUSTRY_{t-j} + \sum_{k=0}^{p_4}\alpha_{4,k}\Delta\ln FDI_{t-k} + \varepsilon_t\end{aligned}$$

$$\begin{aligned}\Delta\ln CO2_t &= \alpha_0 + \sum_{m=1}^{p_1}\alpha_{1,m}\Delta\ln CO2_{t-m} + \sum_{i=0}^{p_2}\alpha_{2,i}\Delta\ln GDP_{t-i} \\ &+ \sum_{j=0}^{p_3}\alpha_{3,j}\Delta\ln INDUSTRY_{t-j} + \sum_{k=0}^{p_4}\alpha_{4,k}\Delta\ln FDI_{t-k} + \alpha_5 u_{t-1} + v_t\end{aligned}$$

$$\begin{aligned}\Delta\ln CO2_t &= \alpha_0 + \sum_{m=1}^{p_1}\alpha_{1,m}\Delta\ln CO2_{t-m} + \sum_{i=0}^{p_2}\alpha_{2,i}\Delta\ln GDP_{t-i} \\ &+ \sum_{j=0}^{p_3}\alpha_{3,j}\Delta\ln INDUSTRY_{t-j} + \sum_{k=0}^{p_4}\alpha_{4,k}\Delta\ln FDI_{t-k} + ECM_{t-1} + v_t\end{aligned}$$

where, ECM_{t-1} is correction error, reflecting correction rate towards the steady state in long run.

$$\begin{aligned}ECM_{t-1} &= \Delta\ln CO2_t - \alpha_0 - \sum_{m=1}^{p_1}\alpha_{1,i}\Delta\ln CO2_{t-m} - \sum_{i=0}^{p_2}\alpha_{2,i}\Delta\ln GDP_{t-i} \\ &- \sum_{j=0}^{p_3}\alpha_{3,j}\Delta\ln INDUSTRY_{t-j} - \sum_{k=0}^{p_4}\alpha_{4,k}\Delta\ln FDI_{t-k} - v_t\end{aligned}$$

ECM also shows effect of GDP, INDUSTRY, FDI and lagged correction error on CO_2 emissions in short run.

If correction error is zero, then there is no imbalance between variables and in this case, long-run relationship is determined by cointegration relationship (no error here). However, if correction error is non-zero, it will deviate from equilibrium. If this error is negative, *i.e.*, CO_2 emission is above steady state, it will start to decrease in next period, to correct for correction error, to reach steady state (hence, named ECM). ECM value to calculate rate at which the steady state is reached (aka the rate at which cointegration is reached in long run). ECM estimates on variables that are I(0) or stationary series, so ECM can be estimated using OLS method.

2.3.5. Granger Causality Test

Studies often use Engle and Granger test [43] [54] [55], granger causality test to know between two factors affecting uni-direction or bi-direction together, or not affecting each other.

To ensure that ARDL model is reliable and stable, it is necessary to perform tests the RESET test of Ramsey [56], Lagrange multiplier test to check autocorrelation, heteroscedasticity test, residual stability test through the cumulative sum residual test (CUSUM: Cumulative sum of recursive residuals) and the adjusted cumulative sum residual test (CUSUMSQ: Cumulative Sum of Square of Recursive Residuals).

Variables and unit measurement are shown in **Table 1** and descriptive statistics for variables are shown in **Table 2**.

Table 1. Description of variables in the dataset.

Variable	Unit measurement	Period	Data source
CO_2	Metric tons per capita	Annual data, from 1990 to 2018	World Bank Indicates, 2021
GDP	USD per capita, constant 2015, USD		
FDI	Netflow FDI (% GDP)		
INDUSTRY	Value added (%GDP)		

Table 2. Descriptive statistics of variables.

Indicator	CO_2 (Metric tons per capita)	GDP (GDP per Capita (USD, constant 2015)	INDUSTRY (Value added, %GDP)	FDI (Netflow FDI, % GDP)
Mean	1.12	1300.03	33.44	5.95
Median	1.02	1194.96	33.25	5.48
Maximum	2.70	2456.79	40.21	11.94
Minimum	0.26	541.90	22.67	2.78
Std. Dev.	0.73	572.04	4.54	2.24
Skewness	0.57	0.43	-0.56	0.82
Kurtosis	2.19	2.02	2.80	3.11
Observations	29	29	29	29

3. Results and Discussions

3.1. Overview of Economic Growth, Industrial Production, and Foreign Direct Investment in Vietnam

1) Vietnam economic growth

Figure 1 represents GDP growth rate from 2009 to 2020. In which, the growth rate of gross domestic product in period 2016-2019 is quite high, at an average of 6.8%/year, among countries with the highest economic growth in region and the world. GDP scale continues to be expanded, by 2020 it is estimated to reach 271.2 billion USD, an increase about 1.4 times compared to 2015; GDP per capita increased over years and in 2020 reached 2779 USD, about 1.3 times higher than in 2015 [57].

Figure 2 showed the growth rate of CO_2 emissions from 1990 to 2018 in Vietnam has increased gradually over years. Vietnam's total CO_2 emissions in 2021 from all sources (including from energy sector, from industrial processes) are 339.8 million tons (accounting for 0.9% of the world) and average per capita is 3447 tons/person. (Figure 3) shows the industry contribution to Vietnam's GDP and its relationship to CO_2 emissions. Since 2000, emissions from energy activities (including transportation, industry and residential) have increased rapidly, accounting for 65% of total emissions compared to 2016. Compared to neighboring countries in Southeast Asia, the emission intensity per unit of Vietnam's GDP is quite high, about 0.35 kg CO_2/1USD [58].

2) Industrial production

According to Office [57], the industry, construction, and service sectors continue to play a leading role, contributing mainly to overall growth. In the period 2011-2020, industry is a sector with the highest growth rate among economic sectors with approximately 30% contribution to GDP. Vietnam from the 50th position (in 2010) to the 22nd position (in 2019) in the world's largest exporting countries. The industry sector is also the largest contributor to state budget.

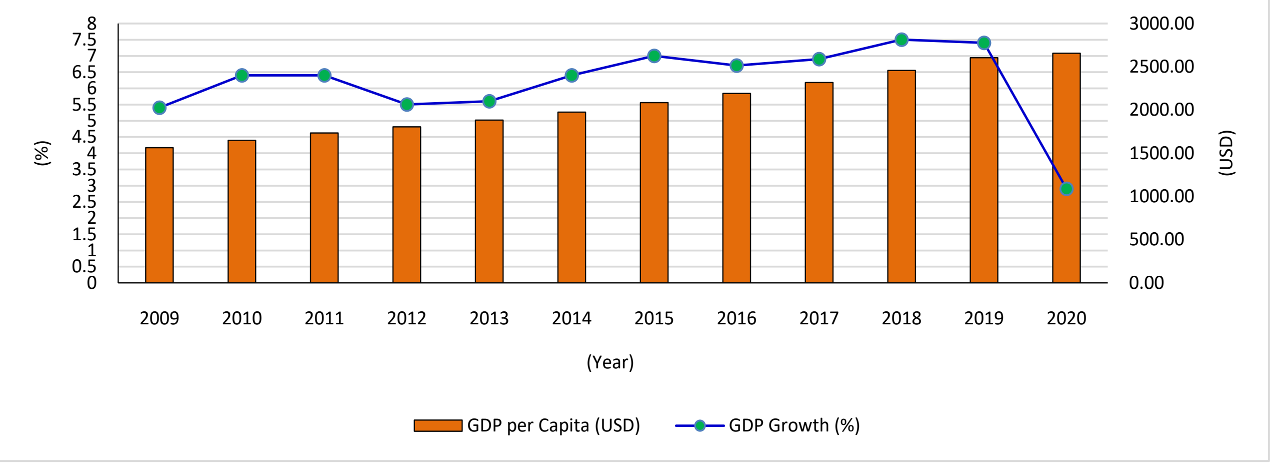

Figure 1. GDP growth and GDP per capita in Vietnam from 2009 to 2020.

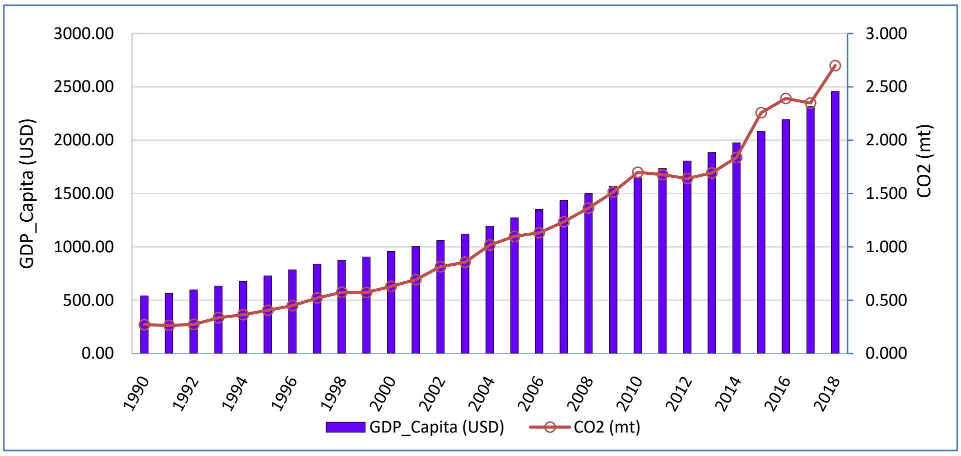

Figure 2. CO_2 emissions, GDP per capita in Vietnam from 1990 to 2018.

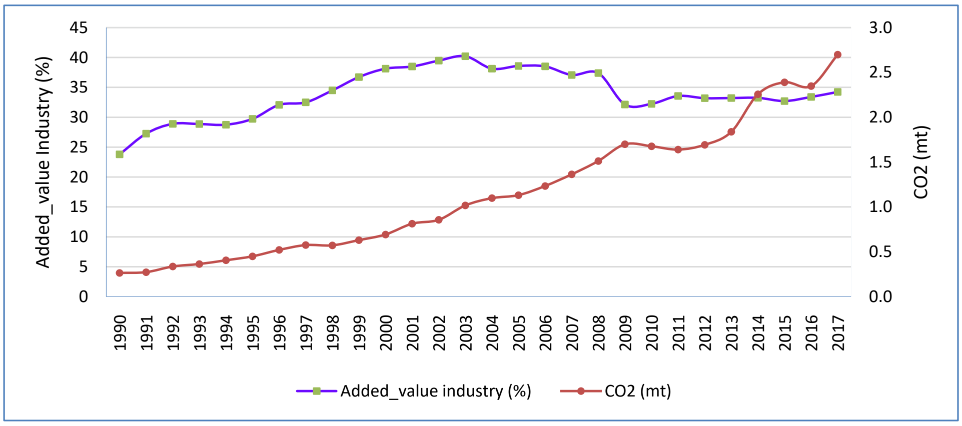

Figure 3. CO_2 emissions, value-added industrial production in Vietnam from 1990 to 2018.

The proportion of processing and manufacturing industry in GDP increased from 13.4% (2016) to 16.7% (2020). Meanwhile, the proportion of the mining industry decreased from 8.1% (2016) to 5.55% (2020). The renewable energy industry is interested in investment, many wind power and solar power projects have been started construction and put into operation.

3) Foreign direct investment capital inflow

Figure 4 showing FDI capital over years, in the period 2011-2020, the average annual realized FDI capital accounts for about 22% - 23% of social investment capital. According to [59], the FDI sector's contribution to GDP was 15.15% (2010) and 18.07% (2015) and 20% (2019). Compared to the world average, the FDI sector's contribution to Vietnam's GDP is 9.4 higher percentage point (20% versus 10.6%). The FDI sector accounts for about 55% of total industrial production value, which has contributed to generate key industries in economy such as telecommunications, oil and gas exploitation, electronics, chemicals, automobiles, and vehicles, machinery, information technology, steel, cement, agro-food processing, leather and footwear, textiles. The FDI enterprises account for a large proportion in high-tech industries such as oil and gas exploitation, electronic industry, telecommunications, office equipment, and computers.

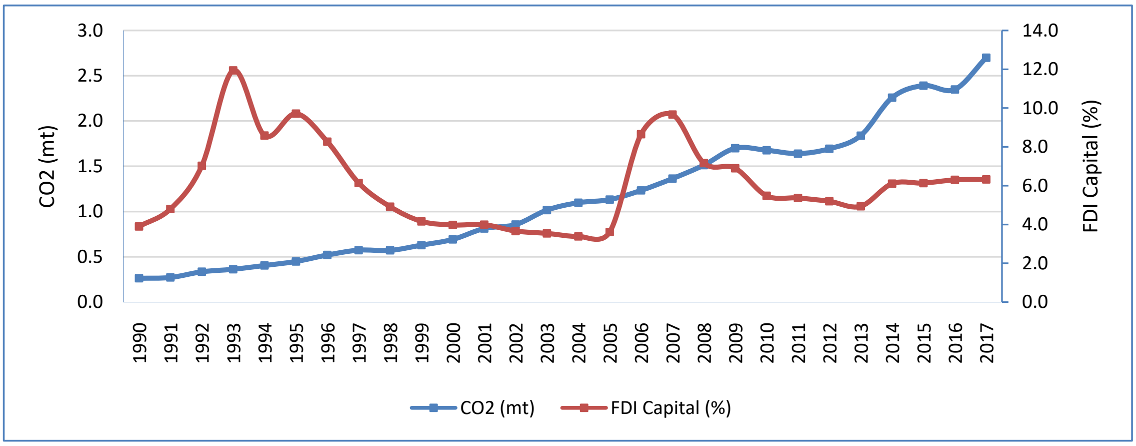

Figure 4. CO_2 emissions, foreign direct investment (FDI) in Vietnam from 1990 to 2018.

3.2. The Relationship between Economic Growth, Industrial Production, Foreign Direct Investment with CO_2 Emissions

3.2.1. Test for Data Stationary

Unit root test to make sure that no variable is stationary at 2nd difference because the regression can be spurious if variables are stationary at 2nd difference, or data is nonstationary. Unit root test according to ADF method of Dickey and Fuller [48] as follows.

Table 3 shows that variables, $\ln CO_2$, lnGDP, lnFDI, lnINDUSTRY, are all stationary, including variable lnINDUSTRY, lnFDI is stationary at level. This shows that ARDL method is appropriate use as described in the methodology section.

3.2.2. Bound Test

Bound test is used to determine cointegration between factors, *i.e.* is understood as the long-run relationship between factors.

Table 4 shows that calculated F-value is greater than upper bound value corresponding to 1% statistical significance level. Thus, it is possible to reject hypothesis H0, accept hypothesis H1: There exists cointegration among variables, or in other words, there is long-term relationship between environmental degradation (proxy by CO_2 emissions) and economic growth, industrial production and FDI.

3.2.3. Estimation of ARDL Model

Overall estimation of ARDL model is to determine the influence of GDP, INDUSTRY and FDI on CO_2 emissions. (Table 5)

The ARDL model between CO_2 emissions with GDP, INDUSTRY, FDI is statistically significant at 1% level. Independent variables GDP, INDUSTRY, FDI are explaining CO_2 emissions. Looking at coefficients, CO_2 emissions are affected by amount of CO_2 from the previous year with statistical significance at 10%, affected by GDP per capita in previous year and current year (statistical significance at 1%), affected by industrial production from previous year (statistical significance 1%).

Table 3. Unit root test. Null Hypothesis: The variable has a unit root.

Variable	Constant without trend		Order of integration
	Level	First Difference	
$lnCO_2$	-0.6468^{ns}	-4.9947^{***}	I(1)
lnGDP	-1.9685^{ns}	-2.7498^{*}	I(1)
lnFDI	-1.5834^{ns}	-3.8873^{***}	I(0)
lnINDUSTRY	-2.7685^{*}	-4.1393^{***}	I(0)

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

Table 4. Bound test result. Null Hypothesis: No levels relationship.

No. of variable (K)	F-statistic	F-Bounds Test (Intercept and no trend)					
		90%		95%		99%	
		I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
3	9.0918	2.72	3.77	3.23	4.35	4.29	5.61

Table 5. Result regression of ARDL model on the relationship between economic growth, industrial production, FDI capital and CO_2 emissions. Dependent Variable: $LNCO_2$; Method: ARDL; Selected Model: ARDL (4, 1, 1, 3).

R-squared	0.9984	Akaike info criterion	−3.6170
Adjusted R-squared	0.9968	Schwarz criterion	−2.9832
Log likelihood	58.2124	Hannan-Quinn criter.	−3.4412
F-statistic	628.2044	Durbin-Watson stat	2.6760
Prob (F-statistic)	0.0000		

Variable	Coefficient	Std. Error
$lnCO_2(-1)$	0.3589^{*}	0.1758
$lnCO_2(-2)$	−0.2275	0.1843
$lnCO_2(-3)$	−0.3332	0.1949
$lnCO_2(-4)$	0.3041^{*}	0.1560
lnGDP	3.7793^{***}	1.1198
lnGDP(−1)	-2.3771^{*}	1.2925
lnINDUSTRY	0.0671	0.2481
lnINDUSTRY(−1)	0.7236^{***}	0.2222
lnFDI	0.0401	0.0390
lnFDI(−1)	0.0189	0.0449
lnFDI(−2)	0.0514	0.0440
lnFDI(−3)	0.0601	0.0363
C	−13.2261	2.7474

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

3.2.4. Estimation of the Long-Run Relationship

Table 6 presents results of estimating long-run coefficients in ARDL model with lag (4, 1, 1, 3). In the long run, all variables have a positive impact on CO_2 emissions, with statistical significance at 1%. This means that, in the long run, if GDP changes by 1%, CO_2 will increase by 1.56%; similarly, if industry increases by 1%, CO_2 emissions increase by 0.88%; FDI increases by 1%, CO_2 emissions up 0.19$%.

3.2.5. Error Correction Model

To analyze the effect of the short-term trend, change and consider relationship between environmental degradation (via CO_2 emission variable) and economic growth, industrial production, and whether FDI can achieve steady state. This study using error correction model (ECM). Table 7 presents the estimated results in the short-term coefficients from ARDL model with selected lags.

In terms of other factors being held constant, with ECM (CointEq(−1)) = −0.8976 with 1% statistical significance. The CO_2 growth rate must be reduced to 89.76% compared to the previous period to achieve the steady state between CO_2 factor and economic growth, industrial production, FDI. Correction error confirmed existence of cointegration relationship as in bound test. This explains, trend toward the steady state can occur, that is, economic growth with trend of reducing CO_2 emissions. In ECM explains 74% of variation CO_2 emissions by economic growth, industrial production, and FDI in Vietnam.

3.2.6. Tests for ARDL Model

1) Model fit test

Tests were introduced to check for autocorrelation, heteroskedasticity. Result presented that the model has no autocorrelation phenomenon (Table 8). Similarly, the model also does not have Heteroskedasticity (Table 9).

2) Test of model residual

Test CUSUM: Cumulative sum of recursive residuals (Figure 5) and CUSUMQ: Cumulative sum of square of recursive residuals (Figure 6) both show that the cumulative sum of residuals and the adjusted cumulative sum of residuals are both within standard range at 5% significance level, so it can be concluded that model residuals are stable, thus, the model is stable.

3.3. Granger Causality Test

The study uses Granger Causality test to see if there is a positive relationship between CO_2 emissions and economic growth and other factors in model. Test results are shown in Table 10.

The results show that economic growth has an effect (causal effect) on CO_2 emissions, but CO_2 emissions have not led to a restraining of economic growth.

Industrial production affects CO_2 emissions, and CO_2 emissions affect industrial production, this is a bi-direction relationship, at level of 10% statistical significance.

There is no relationship between FDI capital and CO_2, which explains that

FDI has not led to environmental degradation, or in other words, FDI factories have not generated excessive CO_2 emissions.

Table 6. Estimation of the long-run relationship in ARDL model. Dependent Variable: $LNCO_2$.

Variable	Coefficient	Std. Error
lnGDP	1.5621***	0.0271
lnINDUSTRY	0.8808***	0.2578
lnFDI	0.1901**	0.0853

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

Table 7. Error Correction Model. Unrestricted Constant and No Trend.

R-squared	0.8365	Akaike info criterion	−3.8570
Adjusted R-squared	0.7384	Schwarz criterion	−3.3694
Log likelihood	58.2124		
F-statistic	8.5285		
Prob(F-statistic)	0.0002		

Variable	Coefficient	Std. Error
C	−13.2261	1.9567
$d(lnCO_2(-1))$	0.2566^{*}	0.1269
$d(lnCO_2(-2))$	0.0291^{ns}	0.1309
$d(lnCO_2(-3))$	-0.3041^{**}	0.1109
d(lnGDP)	3.7793^{***}	0.7399
d(INDUSTRY)	0.0671^{ns}	0.1537
d(lnFDI)	0.0401^{ns}	0.0297
d(lnFDI(-1))	-0.1116^{***}	0.0299
d(lnFDI(-2))	-0.0601^{**}	0.0270
CointEq(-1)*	-0.8976^{***}	0.1331

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

Table 8. Autocorrelation test.

Breusch-Godfrey Serial Correlation LM Test: Null hypothesis: No serial correlation at up to 2 lags			
F-statistic	2.3561	Prob. F (2, 5)	0.1902

Table 9. Heteroskedasticity test.

Heteroskedasticity Test: Breusch-Pagan-Godfrey Null hypothesis: Homoskedasticity			
F-statistic	1.9334	Prob. F (18, 7)	0.1900

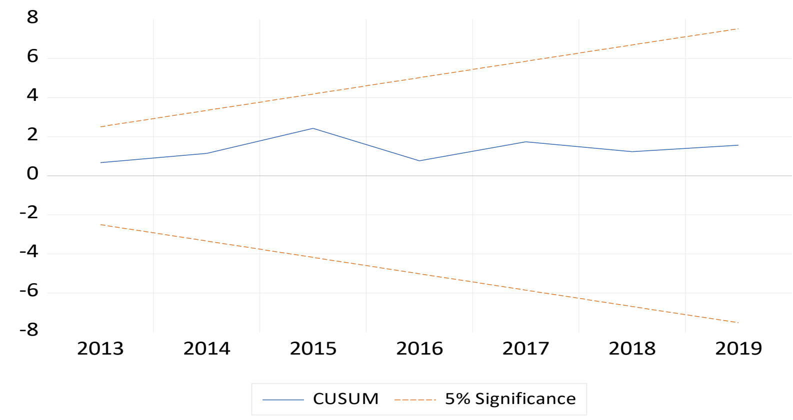

Figure 5. CUSUM: Cumulative sum of recursive residuals.

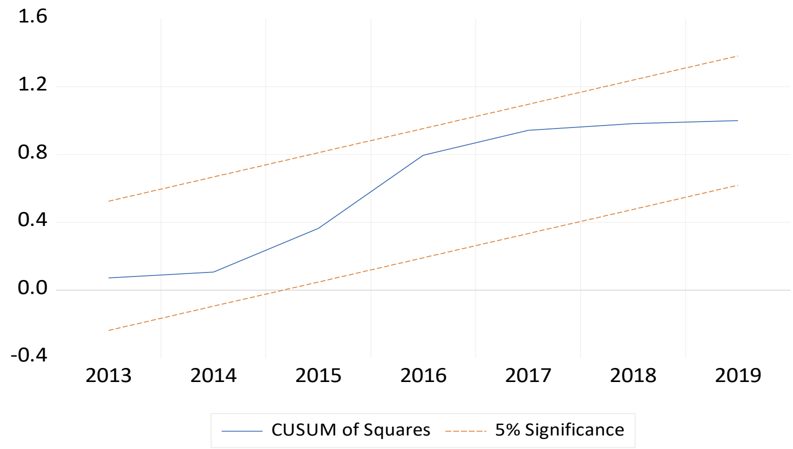

Figure 6. CUSUMQ: Cumulative sum of square of recursive residuals.

Table 10. Result granger causality test. pairwise granger causality tests.

Null Hypothesis	F-Statistic
lnGDP does not Granger Cause $lnCO_2$	4.7303^{**}
$lnCO_2$ does not Granger Cause lnGDP	0.2542^{ns}
lnINDUSTRY does not Granger Cause $lnCO_2$	2.9423^{*}
$lnCO_2$ does not Granger Cause lnINDUSTRY	3.1803^{*}
lnFDI does not Granger Cause $lnCO_2$	0.0880^{ns}
$lnCO_2$ does not Granger Cause lnFDI	0.1204^{ns}

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

4. Discussion and Policy Implications

From the regression results, factors of economic growth, industrial production and foreign direct investment all affect CO_2 emissions in the long run. Simultaneously, correction error model results have confirmed that the above factors tend to converge to reach a steady state. That means CO_2 emissions will tend to decrease in next period. This study, once again, confirmed Environmental Kuznets Curve hypothesis (EKC), economic growth at the expense of environmental quality. This result is similar to the findings recent studies [60] [61] [62] [63]. In fact, according to data from the Vietnam Ministry of Natural Resources and Environment, by 2010, Vietnam's greenhouse gas emissions are about 247 million tons, it is forecasted that by 2020, greenhouse gas emissions will be 466 million tons, but in 2016, the estimated GHG emissions were 423 million tons. Thus, the average growth in greenhouse gas emissions from 2010-2016 was about 8%, faster than the average GDP growth rate of about 6.2% during this period.

Industrial production: In 2021, the contribution from industry and construction sector accounts for 37.86% Vietnam's GDP (Vietnam GSO, 2022). There are two sectors, the processing and manufacturing industry and the export product manufacturing industry, which are generating large amounts of emissions. Specifically, the processing and manufacturing industry generate three times more greenhouse gases than the world average. The export product manufacturing industry causes the largest amount of GHG emissions in Vietnam, accounting for over 50% of total greenhouse gas emissions [64]. In terms of trend, in 2000, agriculture was the largest source of greenhouse gas emissions, accounting for 43.1%, followed by energy at 35%, but since 2010, the energy industry has become the largest source of emissions, increase by 2 times [65].

Regarding foreign direct investment: Although variable FDI sign is positive and statistically significant. However, the Granger Causality test shows that there is not enough evidence to conclude that foreign direct investment has an impact on CO_2 emissions in Vietnam. This conclusion coincides with other studies [66] [67], but different from results of some previous studies [68] [69]. From 1990-2018, Vietnam was a place of "Pollution Haven Hypothesis", because of the weak regulations on controlling environmental pollution, FDI enterprises have medium technology, consume a lot of resources, have not used clean inputs, large emissions, such as metallurgy, chemical manufacturing, textiles, leather [70]. At the same time, the foreign investment sector contributes 20.13% of GDP, accounting for 72% of total export value and about 50% of industrial output, however, the spillover effect from FDI investors on economy is still low. FDI enterprises have not created linkages and have not transferred technology to domestic enterprises [71].

The policy implications here are pointed out: In terms of economic growth, Vietnam is approaching the zero carbon target, and the economy can still emit greenhouse gases, however, it must be offset by activities to eliminate greenhouse gases such as afforestation or carbon capture technology. According to emission under Vietnam's normal development scenario, by 2050 Vietnam's total greenhouse gas emissions are forecast to reach 1495.4 million tons of CO_2eq, in which, the energy sector, is 1210 million tons of CO_2eq, accounting for 81%; agriculture accounts for 10%. So, the energy industry will be decisive in terms of total emissions and zero carbon target [72]. Therefore, policy suggestions such as economical, efficient energy use, establish and operate the carbon credit exchange from 2025, regulate the consumption of greenhouse gases in industrial production, levy a high carbon tax if using materials that generate large emissions [73]. In industry, Vietnam must develop renewable energy, clean inputs, gradually replacing fossil energy. For FDI, in the coming time, attracting FDI should be selective in high-tech fields, use clean input, when entering Vietnam, FDI investors are necessary to create links and transfer technology to domestic enterprises [74].

5. Conclusion

The ARDL model and causality test have confirmed that economic growth reduces the environment quality through CO_2 emissions in Vietnam. However, Vietnam is still aiming for economic growth, industrial development, and commitment to a zero carbon target. Thus, there are some policy implications such as enhancing economical and efficient use of energy, developing high-tech industry, industry using clean inputs, attracting FDI projects with modern technology, be careful when choosing foreign investors. This study will continue to be expanded to evaluate the relationship between factors by NARDL estimation method to see the nonlinear relationship and shocks affecting economic growth and CO_2 emissions.

Ethical Approval

This article does not contain any studies with human participants or animals performed by any of the authors.

Data Availability Statement

The data that support the findings of this study are available from the first author, upon reasonable request.

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Conflicts of Interest

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

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