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The impact of environmental tax, economic growth and renewable energy on CO_2 emissions in Vietnam: Evidence from a VECM approach

Le Thi Nhung[1+]
Bui Thi Minh Nguyet[2]
Pham Quynh Mai[3]
Ha Thi Lien[4]

[1]*Academy of Policy and Development, Vietnam.*
[1]*Email: nhunglt@apd.edu.vn*
[2,3,4]*Academy of Finance, Vietnam.*
[2]*Email: buiminhnguyet@hvtc.edu.vn*
[3]*Email: maipqkinhte@hvtc.edu.vn*
[4]*Email: hathilien@hvtc.edu.vn*

(+ Corresponding author)

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ABSTRACT

The research assesses the impact of environmental taxes, economic growth, and renewable energy consumption on CO_2 emissions in Vietnam during the period 2001-2023. Based on the externality theory, the Environmental Kuznets Curve, and sustainable development theory, the study constructs a Vector Error Correction Model to analyze the dynamic relationships between variables in both the short and long term. The test results indicate that all data series are stationary after first-order differences, with between one and four cointegration relationships among the variables. Empirical analysis reveals that, in the long run, environmental taxes and renewable energy consumption have positive and statistically significant effects on CO_2 emission control, whereas GDP per capita growth exhibits a negative and strong effect. In the short term, only environmental taxes demonstrate an immediate regulatory effect, while GDP and renewable energy do not clearly influence emission control. The error correction coefficient is negative and significant, confirming the existence of a long-term equilibrium adjustment mechanism. Additionally, Granger causality tests show that environmental taxes and economic growth are drivers of CO_2 emission behavior. Variance decomposition highlights the dominant role of GDP, while the impact of renewable energy remains limited. Based on these empirical findings, the study proposes policy implications to enhance the effectiveness of tax instruments, promote green investments, expand renewable energy use, and improve policy coordination to control CO_2 emissions, thereby supporting sustainable economic development in Vietnam.

Contribution/Originality: Our research provides the first empirical evidence in Vietnam on the simultaneous relationship between environmental taxes, economic growth, and renewable energy consumption with CO_2 emissions, both in the short and long term. Methodologically, our research applies the Vector Error Correction Model (VECM), which not only identifies the main drivers but also clearly distinguishes between the immediate and cumulative effects, thereby elucidating the adjustment mechanism of environmental equilibrium during the development process.

1. INTRODUCTION

Carbon dioxide (CO_2) emissions are a global concern, since this greenhouse gas accounts for more than half of total global emissions and plays a central role in global warming (Nguyen, 2012). In this context, the relationship between CO_2 emissions, environmental taxes, economic growth, and renewable energy consumption has increasingly become a central topic in environmental economics research.

Environmental Kuznets Curve (EKC) theory suggests that in the early stages of economic development, emissions tend to increase due to increased industrialization and dependence on fossil fuels, before declining as the economy reaches a threshold of income and develops clean technology (Grossman & Krueger, 1995; Lin & Li, 2011). Environmental taxes are considered an effective fiscal tool in internalizing environmental externalities and reorienting polluting consumption-production behavior. Empirical studies in many countries, such as Sweden, Germany, and China, show that the application of environmental taxes helps to significantly reduce CO_2 emissions through the mechanism of pricing environmental costs and creating incentives for technological change (Polat & Polat, 2018; Rodríguez, Robaina, & Teotónio, 2019; Wissema & Dellink, 2007). In addition, policies to encourage the consumption of renewable energy, such as solar power and wind power, have been proven to be effective in reducing CO_2 emissions in many developed and developing countries (Andersson, 2019; Hao, Umar, Khan, & Ali, 2021).

In Asia, CO_2 emissions are expected to increase rapidly amid strong economic growth and high dependence on fossil fuels. In 2010 alone, five countries, Indonesia, Malaysia, the Philippines, Thailand, and Vietnam, contributed 90% of greenhouse gas emissions in Southeast Asia (Asian Development Bank (ADB), 2015). In Vietnam alone, CO_2 emissions increased from 177 million tonnes of CO_2 equivalent in 2005 to over 370 million tonnes in 2023 (EDGAR, 2024), reflecting the trend of rapidly increasing emissions associated with economic growth. In that context, the Government of Vietnam has made many institutional efforts, notably the approval of the updated Nationally Determined Contribution (NDC) in 2020, with the target of reducing greenhouse gas emissions by 9% compared to the business-as-usual (BAU) scenario using domestic resources and possibly reaching 27% with international support (Ministry of Natural Resources and Environment (MONRE), 2020). In the 2021-2030 period, the NDC strategy prioritizes the reduction of emissions in the energy, agriculture, industry, land use-forestry, and waste sectors.

Although there have been several studies in Vietnam analyzing individual factors affecting CO_2 emissions, such as GDP, energy, or FDI (Nguyen, Aviso, Le, & Tokai, 2018; Thanh & Khuong, 2017), no study has systematically and quantitatively assessed the combined impact of environmental taxes, economic growth, and renewable energy consumption on CO_2 emissions. This gap is especially significant in the context of Vietnam's accelerating transition to a green economy and the need for appropriate policy solutions to balance economic growth and environmental protection.

The main contribution of this research is to provide the first empirical evidence in Vietnam on the simultaneous relationship between environmental taxes, economic growth, and renewable energy consumption with CO_2 emissions, both in the short and long term. By applying the Vector Error Correction Model (VECM), the research not only identifies the main drivers but also clearly distinguishes between the immediate and cumulative effects, thereby elucidating the adjustment mechanism of environmental equilibrium during the development process.

The research is expected to provide a scientific basis for the design of fiscal and energy policies and contribute to the academic literature on green transition in developing countries. The remaining structure of the paper is organized as follows: Section 2 presents the theoretical background and research overview; Section 3 describes the research methodology; Section 4 presents the empirical results and discussion; finally, Section 5 draws conclusions and policy implications.

2. THEORETICAL BACKGROUND AND RESEARCH OVERVIEW

2.1. Theoretical Background

The relationship between greenhouse gas emissions and economic-environmental factors such as environmental taxes, economic growth, and renewable energy consumption has a solid theoretical foundation in welfare economics and sustainable development. The negative externality theory (Pigou, 1932) argues that activities that pollute the environment create social costs greater than private costs, thus requiring government intervention through fiscal instruments such as environmental taxes to internalize these costs. The "polluter pays" principle (Organisation for

Economic Co-operation and Development (OECD), 1972) continues to expand the basis for environmental tax policies, both to price polluting behavior and to create financial resources for green infrastructure and technology development (Falcone & Sica, 2019; Wang & Zhi, 2016).

In addition, the EKC theory provides a theoretical framework to explain the nonlinear relationship between economic growth and environmental pollution. According to the EKC, environmental emissions tend to increase in the early stages of development due to industrialization and the expansion of fossil fuel consumption, and then decrease as the economy reaches a higher level of development, thanks to technological innovations, structural transformation, and increased environmental awareness (Grossman & Krueger, 1995; Lin & Li, 2011). However, the effectiveness of the EKC rule depends on regulatory factors such as environmental policies, institutional capacity, and the level of access to clean technology (Bruvoll & Larsen, 2004).

In energy theory, sustainable development models emphasize the role of renewable energy in replacing carbon-intensive fossil fuels. As the share of renewable energy increases in the consumption structure, CO_2 emissions tend to decrease due to reduced dependence on coal, oil, and gas (Andersson, 2019; Hao et al., 2021). However, the efficiency of renewable energy also depends on the scale of investment, the level of grid integration, and accompanying support policies such as preferential taxes and capital funding.

Based on the theoretical foundations mentioned above, this research builds three test hypotheses:

Hypothesis H1: Environmental taxes have a positive impact on CO_2 emission control.

Hypothesis H2: Economic growth increases CO_2 emissions in the early stages.

Hypothesis H3: Renewable energy consumption has a positive impact on CO_2 emission control.

2.2. Research Overview

International research has documented a substantial body of empirical evidence supporting the role of environmental taxes in controlling CO_2 emissions. Wissema and Dellink (2007); Polat and Polat (2018) and Rodríguez et al. (2019) show that countries that have adopted environmental taxes, such as Sweden, Ireland, and China, have achieved significant emission reductions. Studies have also documented a "green dividend" effect, where environmental taxes not only reduce pollution but also encourage technological innovation and improve social welfare (Aydin & Esen, 2018; Hao et al., 2021).

Regarding economic growth, many studies confirm a positive relationship between per capita GDP and CO_2 emissions in developing countries (Alam, 2014; Lee, Pollitt, & Ueta, 2012). Research conducted in China (Li, Dong, Xue, Liang, & Yang, 2011), Pakistan (Rehman, Rauf, Ahmad, Chandio, & Deyuan, 2019) and Saudi Arabia (Alshehry & Belloumi, 2015) has also affirmed a long-term, positive association between economic expansion and environmental degradation, especially in the absence of effective regulatory interventions.

Conversely, the impact of renewable energy on emissions has been found to be negative, indicating its potential to reduce pollution. Andersson (2019); Yi and Li (2018) and Zhang, Anwer, Hafeez, Jadoon, and Ahmed (2023) observed that in European countries and G7 economies, increases in the share of renewable energy consumption are associated with notable declines in CO_2 emissions, particularly when supported by favorable tax and financial policies.

In the context of Vietnam, several studies have examined the macroeconomic determinants of CO_2 emissions. Nguyen et al. (2018) investigated various influencing factors, while Thanh and Khuong (2017) analyzed the relationships between emissions, growth, energy use, and finance. However, most existing research has focused on individual factors in isolation, lacking an integrated quantitative framework that incorporates environmental fiscal policy, economic growth, and energy transition.

This research addresses this gap by employing a VECM to jointly assess the short-run and long-run effects of environmental tax, economic growth, and renewable energy consumption on CO_2 emissions in Vietnam during the period 2001–2023.

3. METHODOLOGY

3.1. Data and Data Sources

This research employs an annual time series dataset spanning the period from 2001 to 2023 to analyze the relationship between environmental taxation, economic growth, renewable energy consumption, and CO_2 emissions in Vietnam. This is the period that has witnessed a rapid increase in CO_2 emissions in Vietnam, along with the industrialization and integration process (Asian Development Bank (ADB), 2015; EDGAR, 2024) and is also the period when the Vietnamese Government has implemented a series of climate change response policies, including the updated NDC in 2020 (Ministry of Natural Resources and Environment (MONRE), 2020). In addition, the length of the data series during this period is also suitable for the requirements of estimating a time series model with stability and cointegration capabilities (Gujarati, 2003).

The dataset comprises four key variables reflecting environmental, economic, and energy-related dimensions, as described below:

CO_2 emissions (CO2): The dependent variable in the model, measured as the total amount of carbon dioxide emitted, expressed in million tons of CO_2 equivalent. Data is sourced from the World Bank's publicly available database.

Environmental tax revenue (TAX): This variable represents environmental fiscal policy and reflects the magnitude of government revenue from environmental protection taxes, measured in thousand billion Vietnamese Dong. Data are compiled from reports published by the General Department of Taxation of Vietnam.

Per capita GDP (GDP): Representing the level of economic development, measured in current USD. Data is obtained from the World Bank.

Renewable energy consumption (REN): Indicates the share of renewable energy in total national energy consumption (in percentage terms). Data is extracted from World Bank energy statistics.

The selection of variables in the model is based on the theoretical framework of internalization of external costs (Pigou, 1932) the EKC theory Grossman and Krueger (1995), and empirical studies on the role of renewable energy in reducing emissions (Lin & Li, 2011; Shahbaz, Tiwari, & Nasir, 2013). Environmental taxes are considered an effective fiscal instrument to regulate polluting behavior (Tiezzi, 2005), while economic growth is a central element of the development-environment nexus, renewable energy, with its low-emission characteristics, is increasingly emphasized as a pillar of the green transition (Lyons, Durrant, & Kochhar, 2021).

All variables are transformed into natural logarithms prior to estimation to normalize the data, stabilize variance, and approximate normality, thus fulfilling key assumptions of dynamic econometric modeling. The logarithmic transformation also enables the interpretation of estimated coefficients as elasticities, thereby enhancing the comparability and practical significance of the empirical results.

3.2. Vector Error Correction Model- VECM

To test and analyze the dynamic relationship between CO_2 emissions, environmental taxes, economic growth, and renewable energy consumption in both the short and long run, this research applies the VECM model, which is suitable for economic data series that are non-stationary and have a long-term cointegration relationship (Enders, 2014; Johansen, 1988). This model is especially suitable in the case where the time series variables are not stationary at the origin but are co-stationary after first-order differences [I(1)] and there are cointegration relationships between them. VECM allows separating short-term and long-term effects between variables and, at the same time, measures the adjustment mechanism back to equilibrium, which is especially necessary in studying the effectiveness of environmental policies that have impacts with lags (Narayan & Smyth, 2005).

The general form of the VECM is specified as follows:

$$\Delta Z_t = \alpha + \Pi Z_{t-1} + \sum_{i=1}^{k-1} \Gamma_i \Delta Z_{t-i} + \varepsilon_t \qquad (1)$$

Where:

$Z_t = [LCO_2, LTAX_t, LGDP_t, LREN_t]$ is a vector of endogenous variables transformed by natural logarithms

Δ denotes the first difference.

$\Pi = \alpha\beta'$ is the error correction matrix, where β is the matrix of cointegrating vectors reflecting the long-run relationship, and α is the correction coefficient matrix showing the speed of return to equilibrium.

Γ_i is the coefficient matrix of the short-run lags.

ε_t is the white noise vector.

k is the optimal lag determined by information criteria, including AIC, SBIC, and HQIC.

The VECM model estimation procedure is performed through the following steps:

Step 1: Test the stationarity of the time series.

The research employs the Augmented Dickey-Fuller (ADF) unit root test to assess the stationarity of each series. Only series that attain stationarity at order one [I(1)] are included in the cointegration test and VECM model.

Step 2: Determine the optimal lag and test for cointegration.

The optimal lag is selected based on the AIC, SBIC, and HQIC criteria. Next, the Johansen cointegration test (Johansen, 1988), including the Trace and Maximum Eigenvalue tests, is performed to determine the number of cointegrating relationships between the variables.

Step 3: Estimate the VECM model.

If a cointegration relationship exists, the VECM model is estimated to analyze two directions of impact simultaneously: (i) short-run dynamics through first-order differences; and (ii) long-run relationships through the Error Correction Term (ECT). The negative and statistically significant ECT indicates the existence of a self-adjusting mechanism to the long-run equilibrium after short-run shocks.

Step 4: Model diagnostics testing.

To assess the reliability of the estimation results, tests including the normal distribution of residuals (Jarque-Bera), autocorrelation (Lagrange Multiplier) test, heteroskedasticity (ARCH) test, and stationarity of residuals are performed.

Step 5: Granger Causality test.

Granger Causality tests are conducted within the VECM framework to determine the direction of causality between the variables, both in the short run and long run.

Step 6: Variance decomposition.

Variance decomposition analysis is applied to assess the relative contribution of explanatory variables to the variation of the dependent variable (LCO2) over time. This method allows for a better understanding of the cumulative and dynamic effects of each factor on CO_2 emissions.

The application of the VECM model in this study not only provides quantitative evidence for the relationship between environmental taxes, economic growth, and renewable energy consumption but also clarifies the differentiation of short-term and long-term impacts, an important factor in designing and implementing sustainable environmental policies in Vietnam.

4. RESULTS AND INTERPRETATION OF RESULTS

4.1. Descriptive Statistics of Data

Before conducting quantitative analysis, the research presents some descriptive characteristics of the variables used in the model, including CO_2 emissions (CO2), environmental taxes (TAX), per capita GDP (GDP), and renewable energy consumption ratio (REN). Descriptive statistics show that CO_2 emissions in Vietnam tend to increase sharply, clearly reflecting the industrialization and modernization process over the past two decades. At the same time, environmental taxes and GDP per capita also recorded significant growth, while the share of renewable energy tended to decrease towards the end of the period, indicating an increasing dependence on fossil fuels. The results are summarized in Table 1.

Table 1. Descriptive statistics of variables in the model.

Variable	Observations	Mean	Std. Dev.	Minimum	Maximum
CO_2	23	189.994	99.785	62.071	372.949
TAX	23	22,637.632	21,549.812	2,192.122	63,075.011
GDP	23	2,089.340	1,269.450	419.206	4,282.089
REN	23	35.365	10.578	18.900	56.100

On average, CO_2 emissions reached approximately 190 million tons, with a substantial standard deviation (~100 million tons), indicating rapid growth and considerable annual variation. Environmental tax revenue averaged VND 22.64 trillion, with a wide range between VND 2.19 trillion and VND 63.08 trillion, reflecting dynamic shifts in policy implementation and taxable activities. Per capita GDP rose steadily from USD 419 to over USD 4,280, averaging around USD 2,089, in line with sustained economic development. Meanwhile, the share of renewable energy consumption averaged 35.37% but declined significantly from 56.1% in 2001 to 24.2% in 2023, suggesting a shift toward fossil fuel dependency.

Figures 1 through 4 further illustrate these dynamics. CO_2 emissions increased sharply, particularly after 2015, corresponding with intensified industrial activities. Environmental tax revenue experienced notable growth after 2010, peaking in 2020, followed by a decline likely tied to economic and policy adjustments. The consistent rise in GDP per capita reflects Vietnam's resilient economic expansion despite external shocks. In contrast, the diminishing share of renewable energy underscores structural challenges in maintaining a clean energy trajectory amid growing energy demand.

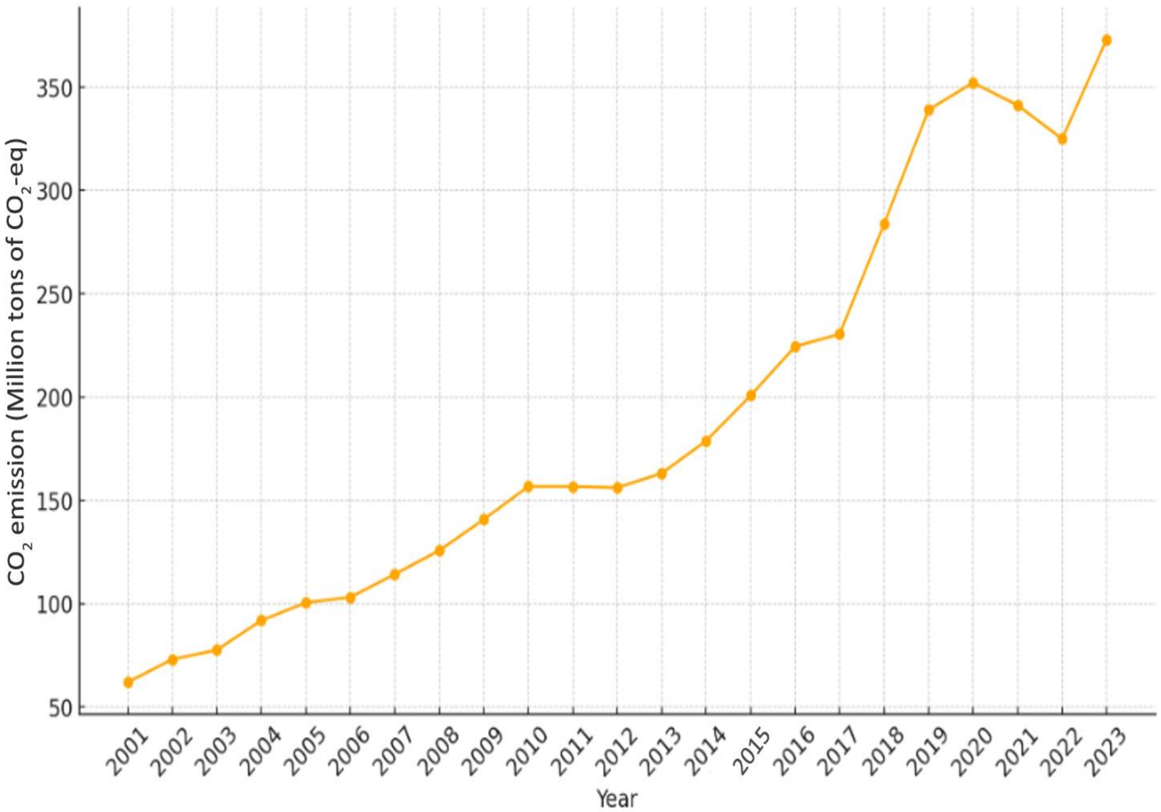

Figure 1. CO_2 emissions (Million tons of CO_2 equivalent), 2001-2023.

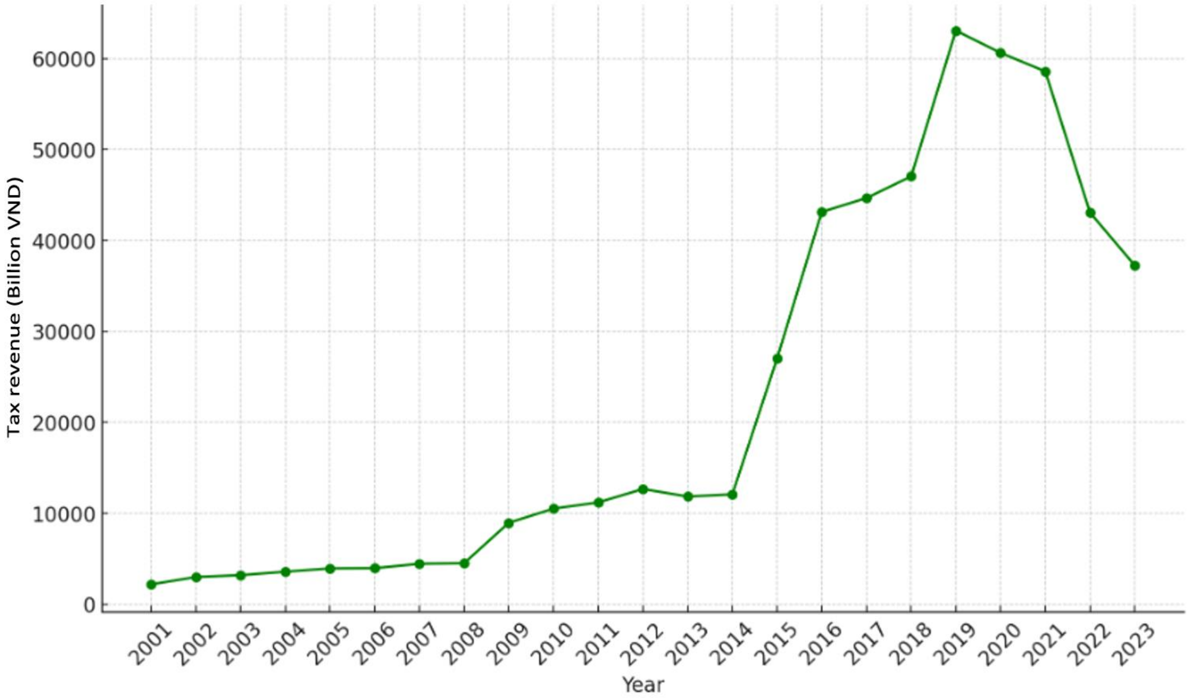

Figure 2. Environmental protection tax revenue (billion VND), 2001-2023.

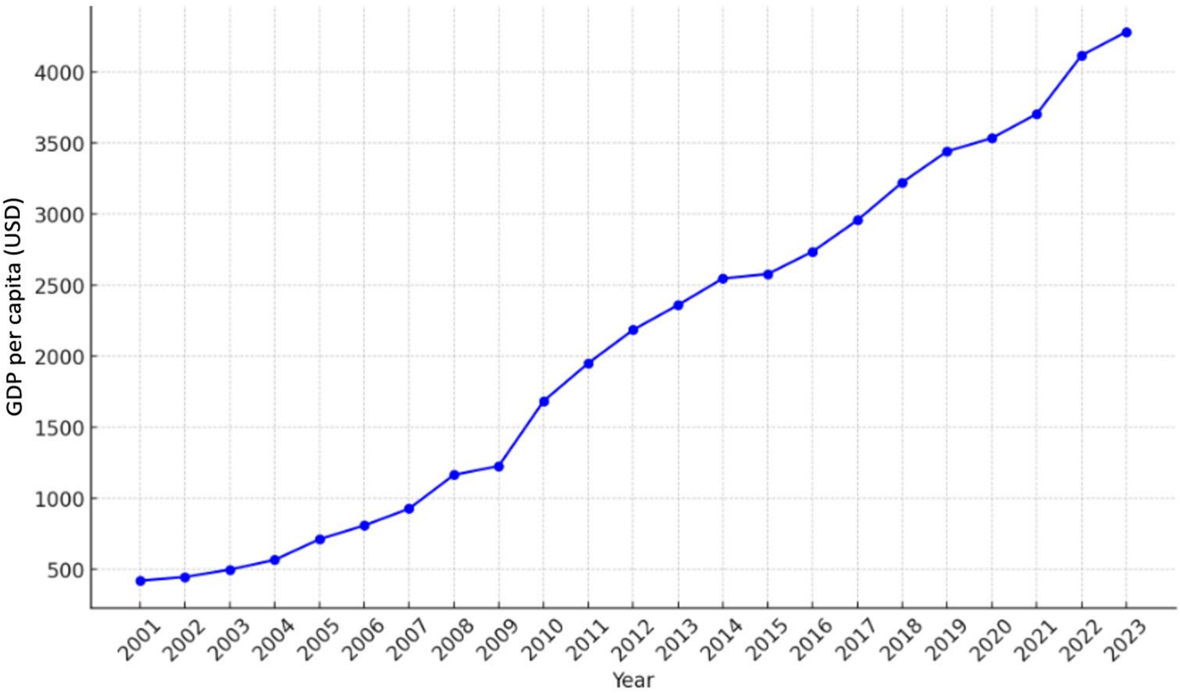

Figure 3. GDP per capita (USD), 2001- 2023.

Figure 4. Renewable energy consumption (%), 2001- 2023.

4.2. Test For Stationarity and Cointegration

4.2.1. Testing the Stationarity

The Augmented Dickey-Fuller (ADF) unit root test is used to test the stationarity of the variables: CO_2 emissions, environmental taxes, economic growth, and renewable energy consumption in Vietnam. The test results are presented in Table 2.

Table 2. Results of the ADF unit root test.

Variable	ADF statistic	P-value	Critical values (t-statistic)		
			1%	5%	10%
LCO_2	-1.007	0.527	-3.786	-3.011	-2.646
LGDP	-1.529	0.3108	-3.786	-3.011	-2.646
LTAX	-1.093	0.359	-3.786	-3.011	-2.646
LREN	-0.468	0.555	-3.786	-3.011	-2.646
$D(LCO_2)$	-3.597	0.016	-3.809	-3.021	-2.650
D(LGDP)	-4.986	0.004	-4.468	-3.645	-3.261
D(LTAX)	-3.428	0.022	-3.788	-3.012	-2.646
D(LREN)	-3.709	0.014	-3.857	-3.040	-2.661

The findings in Table 2 indicate that all variable series are non-stationary in their level form [I(0)]. To address this, the first-difference transformation was applied to examine their stationarity. After differencing, the absolute values of the test statistics exceeded the critical thresholds at the 5% and 10% significance levels, confirming the absence of a unit root. This suggests that the variables become stationary at the first-difference level [I(1)]. Such an outcome provides the foundation for conducting the subsequent cointegration test to assess the presence of a long-run equilibrium relationship among the variables.

4.2.2. Determining Optimal Lags and Johansen Cointegration Test

4.2.2.1. Determine the Optimal Lag

The optimal lag length for the VECM model was selected based on the log-likelihood test. Table 3 shows the results of determining the optimal lag length of the VECM model; accordingly, the optimal lag length is two because this value is recommended by the AIC, SBIC, and HQIC criteria. Therefore, a lag length of two was selected for use when estimating the VECM model.

Table 3. Determining the optimal lag length for the VECM model.

Lag	LogL	LR	FPE	AIC	SBIC	HQIC
0	23.173	NA	0.000	-2.018	-1.819	-1.985
1	97.884	110.101	0.000	-8.198	-7.204	-8.030
2	123.403	26.861*	0.000*	-9.200*	-7.411*	-8.897*

Notes: * Statistically significant at the 5% level
* indicates the lag order chosen based on the respective criterion; LogL refers to the log-likelihood values; LR denotes the sequentially adjusted likelihood ratio test statistics; FPE stands for the final prediction error; AIC is the Akaike Information Criterion; HQIC represents the Hannan-Quinn Information Criterion; and SBIC corresponds to Schwarz's Bayesian Information Criterion.

4.2.2.2. Johansen Cointegration Test

Next, the Johansen cointegration test is performed to check the existence of a long-run relationship between variables. The two methods used are the Trace test and the Max-Eigenvalue test. The results are summarized in Table 4.

Table 4. Johansen cointegration test results.

Method 1: Trace test				
Null hypothesis	**Eigenvalue**	**Trace statistic**	**5% critical value**	**P-value**
None*	0.931	87.527	47.856	0.000
At most 1*	0.672	39.293	29.797	0.003
At most 2	0.543	19.245	15.495	0.013
At most 3	0.248	5.136	3.841	0.023
Method 2: Max-Eigenvalue test				
Null hypothesis	Eigenvalue	Max-Eigen statistic	5% critical value	P-value
None*	0.931	48.233	27.584	0.000
At most 1*	0.672	20.049	21.132	0.070
At most 2	0.543	14.109	14.265	0.053
At most 3	0.248	5.136	3.841	0.023

Notes: * denotes statistical significance at the 5% level.
P-value represents the probability value corresponding to each test statistic.

The results of Table 4 show that the Trace test results indicate up to 4 cointegration relationships at the 5% significance level. Specifically, the Trace statistic exceeds the critical value in all tested hypotheses (p-value less than 0.05), suggesting that the variables share a very close long-run equilibrium relationship. This implies that the factors in the model tend to adjust toward a long-run equilibrium state. Meanwhile, the Max-Eigenvalue test indicates only 1 most significant cointegration relationship at the 5% significance level. This suggests a particularly strong long-run equilibrium relationship compared to the others. The discrepancy between the two tests may be due to their different approaches: the Trace test assesses the overall number of cointegration relationships, while the Max-Eigenvalue test focuses on individual relationships. When the results differ, it is generally advisable to rely on the Trace test, which indicates that there are between 1 and 4 cointegration relationships among the variables in the model. Consequently, the VECM model is suitable for further analysis, as it accommodates both short-run interactions and long-run equilibrium relationships.

4.3. Long-Run Estimation Results

The long-run relationship between CO_2 emissions and the independent variable in the model is determined through the cointegrating equation estimated from the VECM model. The analysis results are shown in Table 5.

Table 5. Long-run VECM estimation results.

Variables	Coefficient	Std. Error	Z	P-value
LTAX(-1)	0.024*	0.016	1.446	0.081
LGDP(-1)	-0.260***	0.013	24.499	0.000
LREN	1.164***	0.048	24.499	0.000

Note: *, *, and *** correspond to statistical significance levels of 10%, 5%, 1%.
Source: Processing results from EViews 10 software

The coefficient estimates yield the following interpretations:

The environmental tax (LTAX) has a negative and statistically significant impact at the 10% level, indicating that as the revenue from environmental protection tax increases, CO_2 emissions tend to decrease. This demonstrates that the tax instrument has contributed to modifying polluting production and consumption behaviors in the long term, thereby confirming the research hypothesis H1 and supporting the "green dividend" theory.

Per capita GDP (LGDP) shows a positive and statistically significant relationship, indicating that economic growth in Vietnam during the study period was accompanied by an increase in CO_2 emissions. This result confirms hypothesis H2 and is consistent with the EKC theory in the early stages of development, when industrialization and consumption expansion are often associated with increased environmental pressures.

The renewable energy consumption ratio (LREN) has a negative coefficient with a very high significance level (1%), reflecting the strong positive impact of clean energy on emission reduction. This contributes to confirming hypothesis H3, showing that the transition to renewable energy is a key factor in sustainable development strategy.

Long-term results confirm that environmental taxes and renewable energy play an important role in reducing CO_2 emissions, while economic growth tends to increase pollution in the absence of effective regulatory mechanisms.

4.4. Short-Term Estimation Results and Error Correction Factor

The short-term relationship between CO_2 emissions and independent variables is analyzed using the VECM model. The estimated results are presented in Table 6.

Table 6. Short-term VECM analysis results.

Variable	D(LCO₂)	D(LTAX)	D(LGDP)	D(LREN)
ECT	-0.982* (0.606)	-2.752*** (1.145)	0.817 (0.665)	-2.655 (2.759)
D(LCO₂(-1))	-0.230 (0.507)	-1.647 (2.045)	-0.012 (0.556)	0.465 (0.635)
D(LTAX(-1))	-0.007** (0.003)	0.046 (0.344)	0.224*** (0.094)	-0.096 (0.107)
D(LGDP (-1))	-0.189 (0.223)	0.374 (0.898)	0.312 (0.244)	0.062 (0.279)
D(LREN(-1))	0.364 (0.446)	-2.367 (1.802)	0.167 (0.490)	0.812* (0.559)
C	0.101** (0.040)	0.121 (0.161)	0.048 (0.044)	-0.027 (0.050)

Note: *, **, and *** represent statistical significance levels of 10%, 5%, and 1% levels, respectively.

The short-run estimation yields several noteworthy findings:

Environmental tax (LTAX) shows a negative and statistically significant impact at the 5% level in the short run, indicating that tax adjustments have an immediate moderating effect on emission behavior. Specifically, when taxes increase, CO_2 emissions tend to decrease, confirming hypothesis H1 and consistent with the hypothesis of rapid response of economic agents to changes in environmental costs.

Per capita GDP (LGDP) and the lagged dependent variable D(LCO2(−1)) do not have significant short-run effects on emissions, implying that the effects of economic growth and inertia in emission behavior are more evident in the long run.

The share of renewable energy consumption (LREN) has a positive and significant effect on itself at the 10% level but does not show a clear effect on CO_2 emissions in the short term. This result may reflect the long-term investment nature and lag in the efficiency of renewable energy.

Thus, in the short term, only hypothesis H1 is confirmed in this research.

The error correction coefficient (ECT) is negative and significant at the 10% level, consistent with theoretical expectations. This result suggests that there is an adjustment mechanism in the economic system: when CO_2 emissions deviate from the long-run equilibrium due to any shock, the system tends to return to the initial equilibrium trajectory. In other words, the CO_2 emissions variable adjusts towards eliminating the deviation, reflecting the endogenous stability of the model in the long run. In terms of magnitude, the coefficient of approximately -1 indicates a fairly rapid adjustment, almost all the deviation is eliminated within one cycle (one year). This suggests that if the tax policy causes a temporary spike in CO_2 emissions, the system will respond strongly to bring emissions back to their appropriate long-term level. This is important evidence confirming the regulatory effect of environmental fiscal policy in directing the economy towards sustainable development. Thus, the ECT coefficient in the VECM model of the research has both theoretical significance, establishing dynamic stability in the relationship between environmental taxes and CO_2 emissions and practical value, reinforcing the argument that environmental taxes in Vietnam not only have immediate impacts but also contribute to directing emission behavior in the long term.

Overall, the short-term results demonstrate the immediate regulatory role of environmental tax instruments. This highlights the need to maintain a stable, coherent, and long-term policy vision to ensure effective control of greenhouse gas emissions.

4.5. Model Diagnostic Testing for VECM

To ensure the reliability and validity of the estimated results from the VECM model, the researchers conducted a series of diagnostic tests to determine whether the model suffers from common defects in time series analysis. The test results are summarized in Table 7.

Normal distribution of residuals: The Jarque–Bera test was applied to assess whether the residuals of the model follow a normal distribution. The results showed that the p-value was 0.6612, which is greater than the threshold of 0.05, thereby failing to reject the hypothesis that the residuals are not normal. This indicates that the residuals of the model have characteristics close to a normal distribution a necessary condition to ensure the reliability of statistical estimates.

Serial correlation: The Lagrange Multiplier (LM) test was used to test for the presence of serial correlation in the residuals. The results obtained with a p-value of 0.6754 showed no evidence of the presence of serial correlation, a factor that often causes bias in coefficient estimates.

Heteroskedasticity: By applying the ARCH test, the research determined the possibility of the existence of heteroskedasticity. The p-value of 0.4299 is not small enough to reject the null hypothesis of no heteroskedasticity. Thus, the variance of the residuals is considered stable.

Stationarity of residuals: An important requirement in the VECM model is that residuals should be stationary. The unit root test for the residuals shows that the p-value of 0.0331, below the 5% significance level, confirms that the residuals are stationary.

Table 7. Summary of model diagnostic test results.

Test	P-value	Conclusion
Normal distribution of residuals (Jarque–Bera)	0.661	The residuals follow a normal distribution
Autocorrelation (LM test)	0.675	No autocorrelation detected
Heteroskedasticity (ARCH test)	0.430	No evidence of heteroskedasticity
Residual stationarity (Unit root)	0.033	Residuals are stationary

From the above results, it can be concluded that the VECM model in the research fully meets the basic econometric assumptions. The absence of common issues such as autocorrelation, heteroskedasticity, or non-normal residual distributions reinforces the stability of the estimates. Therefore, the model can be used to interpret the relationship between environmental taxes and CO_2 emissions consistently and scientifically.

4.6. Granger Causality Test

To determine the direction of impact between variables in the model, the research conducted a Granger test within the framework of the VECM model. Detailed results are shown in Table 8.

Table 8. Granger causality test with VECM models.

Variable	D(LCO$_2$)	D(LTAX)	D(LGDP)	D(LREN)
D(LCO$_2$)		0.648	0.001	0.538
		(0.421)	(0.983)	(0.463)
D(LTAX)	0.007*		5.731*	0.804
	(0.003)		(0.017)	(0.370)
D(LGDP)	0.7186	0.173		0.050
	(0.397)	(0.677)		(0.823)
D(LREN)	0.665	1.724	0.116	
	(0.415)	(0.189)	(0.733)	

Notes: * represents statistical significance level of 5%.

The Granger test results within the VECM model yield several key insights:

There is a statistically significant causal relationship from environmental tax (D(LTAX)) to CO_2 emissions (D(LCO2)) at the 5% level. This suggests that changes in environmental tax policy Granger-cause variations in greenhouse gas emissions, confirming the role of taxation as a forward-looking regulatory tool for influencing environmental behavior. This result provides empirical support for the strategic use of tax policy in emission control.

Conversely, the test does not confirm any significant reverse causality from CO_2 emissions to environmental tax, implying that environmental taxation is not an automatic response to emission fluctuations, but rather a proactive and pre-designed policy instrument aligned with long-term sustainability goals.

Economic growth (D(LGDP)) is identified as a Granger cause of environmental tax (D(LTAX)), suggesting that growth may enhance fiscal capacity and political space for tax reforms or expansion in response to environmental objectives.

There is no statistical evidence to confirm the existence of a causal relationship between the remaining variables (D(LGDP)), (D(LREN)), and CO_2 emissions in this research.

Overall, the Granger causality tests provide important empirical support for the hypothesis that environmental tax and economic growth are key drivers of changes in CO_2 emission behavior in Vietnam.

4.7. Variance Decomposition Analysis

Variance Decomposition (VD) is an important tool in VECM system dynamic analysis, allowing the assessment of the relative influence of independent variables on dependent variables over time. The research conducted variance decomposition for the LCO2 variable across ten forecast periods; the results are presented in Table 9.

Table 9. Variance decomposition table with LCO2.

Period	Std. dev.	LCO_2 (%)	LTAX (%)	LGDP (%)	LREN (%)
1	0.065	100.000	0.000	0.000	0.000
2	0.097	95.439	0.003	0.017	4.539
3	0.116	86.936	5.820	3.745	3.499
4	0.133	84.209	6.833	6.244	2.713
5	0.149	83.777	6.365	7.657	2.201
6	0.164	83.683	6.196	8.088	2.033
7	0.176	82.730	6.638	8.783	1.848
8	0.189	82.116	6.820	9.394	1.670
9	0.200	81.896	6.786	9.780	1.538
10	0.211	81.715	6.798	10.034	1.453

In the initial periods (1–2), the forecast variance of CO_2 emissions is almost entirely explained by its own innovations, with over 95% of the variation attributed to LCO2 itself. This indicates a high degree of short-term self-dependence in CO_2 dynamics, where shocks to emissions have a greater immediate impact than any external factor.

From period 3 onwards, the influence of explanatory variables becomes more prominent:

Per capita GDP (LGDP) exhibits a steadily increasing contribution, reaching approximately 10% by the tenth period. This is consistent with Kuznets's environmental theory in its early stages of development.

Environmental tax (LTAX) maintains a relatively stable explanatory power, accounting for approximately 6–7% across most forecast horizons. This indicates a sustained, though moderate, regulatory effect in shaping emission behavior.

Renewable energy consumption (LREN) contributes the least, explaining under 2% of the variance throughout the period. This limited influence may reflect Vietnam's early-stage energy transition and the still-modest share of renewables in the national energy mix, which is not yet large enough to exert a significant effect on emission dynamics.

The variance decomposition results show that the impact of *environmental taxes and economic growth* on CO_2 emissions tends to increase over time, in which GDP plays a promoting role, while environmental taxes play a restraining role. However, both effects remain moderate, indicating the need for stronger policy enforcement and deeper investment in renewable energy transitions to achieve more effective and sustainable emission control in the long run.

4.8. Discussion of Findings

Quantitative results from the VECM model provide clear empirical evidence of the differential impacts of environmental taxes, economic growth, and renewable energy consumption on CO_2 emissions in Vietnam during the period 2001-2023.

Firstly, environmental taxes show a positive and statistically significant impact on CO_2 emissions control in both the short and long term. This implies that the tax instrument has been somewhat effective in regulating high-emission production and consumption behavior through the social cost adjustment mechanism. The long-term impact level shows a trend of adjusting production and consumption structures towards environmental friendliness, in line with the theory of “green dividend”. However, the magnitude of the impact remains modest, reflecting the limited effectiveness of the policy in the context of uneven enforcement and monitoring capacity. This result is consistent with previous studies such as Polat and Polat (2018); Rodríguez et al. (2019) and Wissema and Dellink (2007).

Secondly, economic growth is confirmed as a driver of CO_2 emissions in the long run, with a positive and highly statistically significant estimated coefficient. This result reinforces the hypothesis of the existence of an early stage in the EKC, when the Vietnamese economy is still in the industrialization phase, heavily dependent on fossil energy and high-emissions-intensive sectors. This finding is consistent with studies in developing economies such as China, Pakistan, and Saudi Arabia (Alam, 2014; Alshehry & Belloumi, 2015; Li et al., 2011). In the short run, GDP has no significant effect on emissions, suggesting that environmental impacts from growth are often cumulative and more pronounced in the medium to long run.

Thirdly, renewable energy consumption has a strong and negative impact on CO_2 emissions in the long term, confirming the role of clean energy as a key element in national emissions reduction strategies. This reflects the cumulative effect of investments in renewable energy infrastructure and technology, as well as the spillover effects on the structure of energy consumption and production. However, in the short term, this variable does not have a significant effect, most likely due to investment lags and the relatively low share of renewable energy in the total consumption structure. This finding is similar to the conclusions of Andersson (2019), Yi and Li (2018) and Hao et al. (2021), which emphasize that renewable energy can only play an effective role in controlling emissions when it reaches a sufficiently large scale and level of integration.

Finally, the Granger test results show that environmental taxes and economic growth are drivers of CO_2 emissions, while there is no evidence of reverse causality. This confirms the active role of fiscal policy and economic development orientation in controlling emission behavior. In addition, variance decomposition shows that in the long run, the impact of GDP on emission fluctuations is larger than that of the remaining factors, reflecting that growth pressure is still the dominant factor in the current development model.

Overall, the empirical results confirm the three research hypotheses. However, the limited effectiveness of environmental taxes and the unclear role of renewable energy in the short term pose urgent requirements for improving policy capacity, perfecting the legal framework, and increasing investment in clean energy infrastructure to realize sustainable development goals in Vietnam.

5. CONCLUSION

This research employed a VECM model to examine how environmental taxes, economic growth, and renewable energy consumption influence CO_2 emissions in Vietnam from 2001 to 2023. The findings indicate that, over the long term, both environmental taxation and the share of renewable energy consumption contribute positively and significantly to reducing CO_2 emissions, whereas growth in GDP per capita is associated with a significant increase in CO_2 emissions. In the short term, environmental taxes are the only variable with a significant effect, implying that such fiscal measures may enable prompt adjustments in emission-related behavior through environmental policy.

The negative and statistically significant ECT confirms the existence of a long-run equilibrium adjustment mechanism between the variables. In addition, the Granger test shows that environmental taxes and economic growth are the driving factors of CO_2 emissions behavior, while renewable energy has not shown a prominent role in the short term. Variance decomposition shows that GDP is the main driver of emission fluctuations, reflecting the increasing environmental pressure in parallel with growth in the absence of effective regulatory mechanisms.

Despite these findings, the magnitude of the mitigating effects remains modest, indicating the need for more robust and integrated policy frameworks. Based on empirical evidence, several policy implications emerge:

First, enhance the effectiveness of environmental tax policy: It is necessary to adjust tax rates and expand the tax coverage to fully reflect the social costs of environmental pollution. At the same time, enhance enforcement capacity and transparency in the use of revenue sources to strengthen trust and policy effectiveness.

Second, design a mechanism to encourage green investment: The State needs to have preferential tax and credit policies for enterprises that innovate technology and shift to low-carbon production and consumption models. Along with that, it is necessary to develop a domestic carbon credit market to create incentives to reduce emissions.

Third, promote renewable energy consumption: Increase investment in smart grid infrastructure, integrate renewable energy, and reform electricity pricing policies to create conditions for clean energy to compete fairly in the market. A long-term strategy is needed to increase the proportion of renewable energy in the national energy structure.

Fourth, combine multiple tools in emission management: closely coordinate fiscal policy (environmental tax), energy policy, and market instruments to create a synergistic effect in emission control and promote sustainable development.

Finally, strengthening institutions and enforcement capacity: Building a system to monitor and evaluate the effectiveness of environmental policies, improving data analysis capacity, and applying digital technology in emission management are key conditions to ensure the success of the above policy solutions.

This research contributes theoretically by quantifying the simultaneous impact of three key factors on CO_2 emissions, while affirming the role of tax instruments and clean energy in Vietnam's green transition. However, the research still has some limitations, including the relatively short data time range and the lack of in-depth analysis of intermediate factors such as technological innovation, consumer behavior, or enforcement institutions. Further studies can expand the model with intermediate variables or analyze at the industry level to provide a more comprehensive and in-depth view.

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