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Investigating The Environmental Quality–Economic Growth Nexus In Vietnam: Nonlinear And Asymmetric Evidence From NARDL And QQR Approaches

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Abstract
Vietnam is facing worsening environmental pollution as its economy grows rapidly. This situation creates an urgent need to better understand the link between development and emissions. This study analysises nonlinear and asymmetric relationship between economic growth and environmental quality in Vietnam from 1987 to 2023. Two methods are used: the Nonlinear Autoregressive Distributed Lag (NARDL) model and the Quantile-on-Quantile Regression (QQR). The carbon intensity of GDP is used as the dependent variable. Key influencing factors include the GDP, renewable energy, and foreign direct investment (FDI), which is divided into positive (FDI^+) and negative (FDI^-) flows. The results confirm the Environmental Kuznets Curve (EKC) hypothesis. GDP squared has a statistically significant negative effect, and the QQR surface shows a clear inverted-U shape. Renewable energy helps reduce CO_2 emissions in both the short run and the long run, especially at higher quantiles. FDI has asymmetric effects: FDI^+ reduces emissions, while FDI^- brings no clear benefit. The QQR results clearly show that the effects of economic growth, renewable energy, and FDI on emissions depend on specific economic and environmental contexts. In other words, the relationship is not fixed–it varies across different levels of development and pollution. This study contributes to EKC theory by combining two advanced methods to explore how each factor affects emissions across different levels. Based on the findings, the study recommends key policy directions: expand renewable energy, apply higher environmental standards in FDI approval, and promote green growth toward Vietnam's 2050 net-zero goal.
Keywords: *Environmental Kuznets Curve (EKC); CO_2 intensity; Economic growth; Renewable energy; Foreign direct investment; NARDL; Quantile-on-Quantile Regression (QQR).*

I. INTRODUCTION

Vietnam has shown a strong commitment to sustainable development by creating long-term environmental strategies (Environment+Energy Leader, 2024). Both the government and the public are becoming more aware that protecting the environment and building a greener Vietnam is a priceless investment for the future (Nguyen Si Dung, 2025). Practical solutions are being promoted, such as expanding the eco-industrial park model to reduce the environmental impact of industrial production (VNA, 2025). At the same time, green production, clean technology, and the circular economy are gaining more attention and being adopted by many businesses (Nguyen Thi Nguyet Minh, 2022). Overall, Vietnam is working hard to balance economic growth with environmental protection, aiming for a more sustainable future. Vietnam's rapid economic growth over the past three decades has boosted industrialization but also increased greenhouse gas emissions. The link between growth and the environment is often explained by the EKC, which suggests that pollution rises with income at early stages but falls after reaching a certain economic threshold (Grossman & Krueger, 1995). However, many studies argue that the EKC does not always apply to developing countries, where green technologies are limited and environmental regulations are still weak (Stern, 2004). According to Reuters, Vietnam's GDP grew strongly by 7.09% in 2024, up from 5.05% in 2023, mainly due to rising exports and increasing in FDI (Khanh Vu & Phuong Nguyen, 2025). However, rapid and poorly controlled development in industries such as textiles, steel, cement, and chemicals has led to a sharp increase in greenhouse gas emissions and severe pollution of air and water, creating a major conflict between economic growth and environmental sustainability (Thanh Thu, 2024). Switching to renewable energy sources like solar, wind, and hydropower is a key strategy to support both economic growth and environmental protection. The government has introduced important policies, including Resolution No. 55-NQ/TW dated February 11, 2020, which outlines national energy development goals through 2030, with a vision to 2045. The plan aims to raise the share of renewable energy to 15–20% by 2030 and 25–30% by 2045, to reduce dependence on fossil fuels and lower CO_2 emissions. Renewable energy projects not only help cut emissions but also promote green economic growth, improve environmental quality, and strengthen national energy security amid fluctuations in global fuel markets. Attracting FDI remains a strategic priority for Vietnam to boost economic growth and support industrial restructuring. In 2023, Vietnam recorded around USD 36.6 billion in registered FDI, up over 32% from 2022, with nearly 67% going into the manufacturing and processing sector (Phuong Anh, 2024). In 2024, disbursed FDI reached a record high of USD 25.35 billion, showing growing international investor confidence in Vietnam's investment environment (VietnamPlus, 2025). However, the rise in FDI also raises environmental concerns, especially the risk of becoming a "pollution haven" if polluting industries relocate from countries with stricter standards to Vietnam without proper control. To reduce this risk and promote sustainable development, the government has prioritized high-quality FDI, encouraged green and eco-friendly projects, and strengthened environmental criteria in investment approval (Le Anh, 2025). This is an important approach to ensure that FDI is not only a driver of growth but also contributes positively to improving environmental quality.

As Vietnam experiences rapid growth while facing worsening environmental pollution, understanding the link between economic growth and environmental quality becomes increasingly urgent. In particular, it is important to examine the roles of renewable energy and FDI—two key factors that are playing a growing role in the country's development. However, most previous studies have used linear approaches, which do not fully capture the nonlinear, asymmetric relationship or how the effects change across different levels of economic growth or emissions. To address this gap, this study combines two methods: (i) the NARDL model to test long-run nonlinear and asymmetric relationships, and (ii) Quantile-on-Quantile Regression (QQR) to examine how the effects of each factor vary across different quantiles of both the independent and dependent variables. This combination helps reveal how economic factors impact the environment quality under different economic conditions— that traditional linear models cannot show. As a result, the study recommend policy insights that support green growth and align with Vietnam's net-zero emissions target by 2050.

II. LITERATURE REVIEW

2.1. Theoretical background

Many previous studies have examined the relationship between economic growth and environmental quality, mostly based on the EKC hypothesis. However, empirical results remain inconsistent. Abid et al. (2024) shows no evidence of the EKC was found in West African countries. The study also highlighted the negative impact of FDI (a "pollution haven" effect) and the positive roles of renewable energy and corruption control. Meanwhile, Freire et al. (2023) confirmed the EKC for CO_2 and N_2O in Brazil, but not for CH_4. In Egypt Khalid et al. (2025) found that the EKC appears only in the short run. In the long run, most factors—such as economic growth, finance, energy use, urbanization, and trade—increased emissions, except for GDP squared. Asongu et al. (2016) did not directly test the EKC but found a two-way causal relationship between GDP, CO_2 emissions, and energy use in 24 African countries.

A common finding is that economic growth tends to harm the environment, especially during the early stages of development. (Yan et al., 2025) using a PSVAR model in the Yellow River Basin (China), confirmed that rapid economic expansion worsens environmental quality. Byaro et al. (2024) using quantile regression with the method of moments across 30 Asian countries, and Jain et al. (2023) in a study covering 180 countries, also confirmed the negative impact of economic growth and population on environmental sustainability. Khan et al. (2024), in a study of 35 Belt and Road Initiative (BRI) countries, also reported the negative impact of GDP growth, while Dzhumashev and Kazakevitch (2025) emphasized the long-term trade-off between economic growth and environmental degradation due to resource dependence.However, this relationship is not linear and can be influenced by factors such as technological innovation, green finance, or effective institutions. Khan et al. (2024) argued that technological innovation can improve environmental quality while still supporting economic growth. Byaro et al. (2024) emphasized the positive moderating role of institutional quality—even for seemingly beneficial factors like renewable energy if it has not yet reached a large enough scale.

Some other notable findings include: Byaro et al. (2024) found that renewable energy can have negative effects on the environment in Asia due to its low usage levels; Jain et al. (2023) pointed out that in some developing countries, a smaller government size may have a positive link with environmental efficiency; while Dzhumashev and Kazakevitch (2025) warned of long-term risks to resources and the environment if proper green policies and technologies are not adopted.

Overall, these studies show that the relationship between growth and the environment is multidimensional, depending on context and policy conditions. However, most of them still rely on linear models or focus on sample averages, which do not fully capture the asymmetric and heterogeneous effects across different levels of growth or emissions. Therefore, combining the NARDL model (for long-term nonlinear analysis) and QQR (for quantile-based impact analysis) in this study is essential to better understand the complex relationship between growth, FDI, renewable energy, and CO_2 emission intensity in the case of Vietnam.

2.2. Selection of factors in the study

In environmental studies, many papers use total CO_2 emissions as the main dependent variable. CO_2 is a common byproduct of industrial activities, especially when fossil fuels are used. CO_2 emissions are often strongly correlated with economic factors such as GDP, trade, FDI, urbanization, and financial globalization (Chen & Wang, 2025; Fakhrullah et al., 2025; Nguyen et al., 2024; Wang et al., 2023). However, this study chooses CO_2 intensity—the amount of CO_2 emitted per unit of GDP to better reflect the link between economic growth and environmental efficiency. Unlike total emissions, which only show the scale of pollution, CO_2 intensity indicates how "green" the growth is, or the ability to decouple economic development from pollution, which aligns with sustainable development goals. This indicator has also been recommended by many recent studies (Behera et al., 2024; Chen & Wang, 2025; Nguyen et al., 2024).

GDP per capita is used to better reflect a country's average living standard, productivity, and development level, rather than just relying on total GDP. Studies have shown that GDP is not only closely linked to emissions but also plays a key role in improving living conditions and supporting sustainable development (Khan, 2024; Li et al., 2025; Sikder et al., 2024; Xuan, 2025). Including the squared GDP variable helps test the nonlinear relationship between growth and the environment—the core of the EKC hypothesis (Grossman & Krueger, 1995).

Renewable energy is a key variable in the context of green transition. Baigorri et al. (2025) found that renewable energy helps reduce the ecological footprint, while Raifu et al. (2025) confirmed a two-way relationship between renewable energy and economic growth. (Nuţă et al., 2024) highlighted its role in improving environmental quality under urbanization. Therefore, renewable energy is a suitable indicator to capture the intersection between economic development and environmental protection. FDI is included as an important channel linking international economic integration with environmental impact. Two competing hypotheses—the "pollution haven" and the "pollution halo"—have been tested in many recent studies. Akhtar et al. (2024) confirmed that FDI worsens environmental quality, while (Bello et al., 2024; Guo et al., 2024) showed that FDI can bring clean technology and promote low-carbon growth under supportive policies. Other studies also found that FDI can support green finance, technological innovation, and sustainable development when accompanied by strong legal frameworks (Ganda & Panicker, 2025; Raihan et al., 2025; Siripi et al., 2024). In summary, the selection of variables in this study—including CO_2 intensity, GDP per capita, GDP^2, renewable energy, and FDI is based on solid theoretical foundations and international empirical evidence. In particular, using CO^2 intensity instead of total CO^2 emissions allows for a more accurate measure of environmental quality from economic activities, reflects resource efficiency, and supports the assessment of Vietnam's green growth strategy.

2.3. Overview of Research Methods

Table 2.1: Comparative Summary of EKC-Related Studies: Variables, Econometric Methods, and Validation

#	Variables (Determinants)	Econometric Approach	Period of Time	Country/Region	Environmental Kuznets Curve Validation	Authors, Year
1	CO_2, EC (Gas), FDI, GDP	ARDL	40 years	Iran	Supported EKC.	Maroufi and Hajilary (2022)
2	CO_2, EG (pc), EG^2, FDI, NRE, RE, URB	Panel unit root tests, panel model	1990-2018	Visegrad Countries	Supported EKC(- GDP, + GDP^2).	Leitão et al. (2023)
3	CO_2, CC, EG, FDI, GOV (PI), IND	Not stated (mentions causal links)	1996-2022	Pakistan	Partially supported (+ GDP → + CO_2; EKC not tested directly).	Akhtar et al. (2024)
4	CO_2, (PCCE), EG (pc), FDI, RE, TO	ARDL, Zivot-Andrews, Bounds Test	1972-2021	Bangladesh	Supported EKC (inverted U-shape).	Rahman et al. (2024)
5	CO_2, EG	OLS, ARDL Bounds Test	1965-2021	E7 Countries *(Indonesia, Türkiye, India, China, Russia, Brazil, Mexico)*	Partially supported (only Indonesia: U-shape; others: N or linear).	Ayık and Özer (2025)
6	CO_2, EC, EG, FDI, RE	AMG	Annual frequency data	South Asian Countries	Supported (inverted U- and N-shape).	Bekun et al. (2024)
7	CO_2, EG, FDI, RE, URB	ARDL bounds test, Granger causality	1990-2018	Vietnam	Supported EKC	Bui Minh et al. (2023)
8	CO_2, EG, EMIX, FDI, POP	AMG	2002-2019	G20 Economies	Not supported EKC	Wang et al. (2024)
9	CO_2, EG, EF, FDI, NATRES, RE	CS-ARDL, PQR	1998-2019	Transition Economies	Not supported (U-shape observed; EKC rejected).	Wencong et al. (2023)
10	CO_2, EC, EG, FDI, R&D, RE	FE, Diff-GMM, Sys-GMM	2000-2020	25 Emerging Markets	Partially supported (EKC not rejected, but pollution path varies with growth).	Odei et al. (2025)

Note: CO_2: Carbon dioxide emissions; CO_2 (PCCE): Per capita carbon emissions; GDP / EG: Economic growth; EG (pc): Economic growth per capita;

EG²: Squared economic growth; FDI: Foreign direct investment; EC: Energy consumption; RE: Renewable energy; NRE: Non-renewable energy;
URB: Urban population; GOV (PI, CC): Governance indicators (Political instability, Corruption control); IND: Industrialization; TO: Trade openness;
EMIX: Energy mix; POP: Population; NATRES: Natural resources; EF: Economic freedom; R&D: Research and development.
ARDL: Autoregressive Distributed Lag; AMG: Augmented Mean Group; OLS: Ordinary Least Squares; GMM: Generalized Method of Moments,
Diff-GMM: Difference Generalized Method of Moments; Sys-GMM: System Generalized Method of Moments;
CS-ARDL: Cross-sectional Autoregressive Distributed Lag; PQR: Panel Quantile Regressio

the review of studies in Table 2.1 shows that the ARDL model and variables such as CO_2, GDP, GDP^2, FDI, and renewable energy are commonly used to test the EKC hypothesis across various countries and time periods. The EKC is mostly confirmed in developing countries, while some studies extend the analysis using both linear and nonlinear models such as VECM, FMOLS, NARDL, or QQR. This reflects the diversity of approaches and highlights the importance of choosing suitable models to analyze the link between economic growth and environmental quality.

This study contributes to the current literature by combining both NARDL and QQR methods. While NARDL tests long-run asymmetric relationships, QQR captures the effects across different quantiles. Together, they provide a more comprehensive view of the relationship between CO_2 emission intensity, GDP, renewable energy consumption, and FDI in the context of Vietnam.

3. METHODOLOGY

3.1. NARDL Method

3.1.1. General and Empirical Model

The ARDL model in time series analysis consists of two main parts: (i) the autoregressive part, where the dependent variable is influenced by its own past values; and (ii) the distributed lag part, where independent variables affect the dependent variable through multiple lagged periods.

The ARDL model was proposed by (Pesaran & Shin, 1999), as shown in Equation 3.1:

$$\mathbf{ARDL\ (q,p)\Delta Y_t = \beta_0 + \underbrace{\sum_{j=1}^{p} \beta_j \Delta Y_{t-j} + \sum_{i=0}^{q} \delta_{1,i} \Delta X_{t-i}}_{Short-run} + \underbrace{\varphi_1 Y_{t-1} + \varphi_2 X_{t-1}}_{Long-run} + \varepsilon_t \quad (Eq.3.1)}$$

Where: ARDL short-run coefficient: β_0; β_j; $\delta_{1,i}$; ARDL long-run coefficient: φ_1; φ_2; Error term: ε_t

NARDL is an extension of the ARDL model developed by Shin et al. (2014) also known as the asymmetric ARDL model because it splits the variables into positive and negative components, as shown in Equation 3.2:

$$\mathbf{NARDL: \Delta Y_t = \beta_0 + \underbrace{\sum_{j=1}^{p} \beta_j \Delta Y_{t-j} + \sum_{i=0}^{q} \delta_i^{+} \Delta X_{t-i}^{+} + \sum_{i=0}^{q} \delta_i^{-} \Delta X_{t-i}^{-}}_{Short-run} + \underbrace{\varphi_1 Y_{t-1} + \varphi_2^{+} X_{t-1}^{+} + \varphi_2^{-} X_{t-1}^{-}}_{Long-run} + \varepsilon_t \quad (Eq.3.2)}$$

Where: NARDL short-run coefficient: β_0; β_j; δ_i^{+}; δ_i^{-}; NARDL long-run coefficients with asymmetric terms: φ_1; φ_2^{+}; φ_2^{-}; Error term: ε_t.

For an independent variable, if the value in the current period is higher than in the previous period, it is considered an increasing trend (Eq. 3.3); if the value is lower, it is considered a decreasing trend (Eq. 3.4).

$$X_t^{+} = \sum_{t=1}^{t} \Delta X_t^{+} = \sum_{t=1}^{t} \max(\Delta X_t, 0) \quad (Eq. 3.3)$$

$$X_t^- = \sum_{t=1}^{t} \Delta X_t^- = \sum_{t=1}^{t} \min(\Delta X_t, 0) \text{ Eq. 3.4)}$$

The standard linear ARDL model is a special case of the NARDL model when the coefficients of the positive and negative components are equal: $\varphi_2^+ = \varphi_2^- = \varphi_2$. Compared to the linear ARDL, NARDL has the advantage of distinguishing between the effects of increases and decreases in a variable, allowing for a more realistic representation of the economic–environmental relationship.

In this study, the relationship between CO_2 emission intensity and other factors is expressed in a simplified form in Equation 3.5.

$$CO2_t = \alpha_0 + \alpha_1 GDP_t + \alpha_2 GDP_t^2{}_t + \alpha_3 RR_t + \alpha_4^+ FDI_t^+ + \alpha_4^- FDI_t^- + \varepsilon_t \text{ (Eq. 3.5)}$$

Variables GDP_t, RR_t, FDI_t are measured in different units, so they are converted into logarithmic form. Accordingly, Equation 3.5 is transformed into Equation 3.6.

$$\ln CO2_t = \alpha_0 + \alpha_1 \ln GDP_t + \alpha_2 (\ln GDP)_t^2 + \alpha_3 RR_t + \alpha_4^+ FDI_t^+ + \alpha_4^- FDI_t^- + \varepsilon_t \qquad \text{(Eq. 3.6)}$$

The NARDL model in this study is estimated using OLS, with lag order p for the dependent variable and q for the independent variables. The NARDL model is presented in Equation 3.7:

$$\begin{aligned} \text{NARDL: } \Delta \ln CO2_t &= \beta_0 \\ &+ \underbrace{\sum_{j=1}^{p} \beta_j \ln CO2_{t-j} + \sum_{i=0}^{q} \delta_{1,i} \ln GDP_{t-i} + \sum_{i=0}^{q} \delta_{2,i} \ln GDP_{t-i}^2 + \sum_{i=0}^{q} \delta_{3,i} \ln RR_{t-i} + \sum_{i=0}^{q} \delta_{4,i} FDI_{t-i}^+ + \sum_{i=0}^{q} \delta_{4,i} FDI_{t-i}^-}_{\text{Short-run}} \\ &+ \underbrace{\varphi_1 \ln CO2_{t-1} + \varphi_2 \ln GDP_{t-1} + \varphi_3 \ln GDP_{t-1}^2 + \varphi_4 \ln RR_{t-1} + \varphi_5^+ \ln FDI_{t-1}^+ + \varphi_5^- \ln FDI_{t-1}^-}_{\text{Long-run}} \\ &+ \varepsilon_t \text{ (Eq. 3.7)} \end{aligned}$$

The symbols *p* and *q* represent the optimal lag lengths for each variable in the model. Lag selection can be based on criteria such as AIC or SIC. In this study, the EViews software is used, which automatically selects the optimal lag for each variable, as suggested by Nsor-Ambala and Amewu (2023). The ε_t is an IID process with zero mean and constant variance, σ_ε^2.

3.1.2. Unit Root Test and Bound Test

a. Unit Root test

In the first step of the NARDL model, it is necessary to check the stationarity of the variables. The variables $\ln CO_{2i}$, lnGDP, lnRR, $\ln FDI^+$, $\ln FDI^-$ are examined for stationarity at level, denoted as I(0) or at the first difference, denoted as I(1). This step is important because if the variables are non-stationary or integrated of order two without proper treatment, the model may produce misleading results. This study uses the Augmented Dickey-Fuller (ADF) test Dickey and Fuller (1979) and the Phillips-Perron (PP) unit root test Peter and Perron (1988) to test the stationarity of the variables.

b. Bound test

In time series analysis, several methods are used to test for cointegration, such as the two-step approach by Engle and Granger (1987), the maximum likelihood method by Johansen (1988), and the Phillips-Ouliaris test (Phillips & Ouliaris, 1990). However, these methods require that all variables in the model be integrated of the same order. If the model contains both I(0) and I(1) variables, the results may be unreliable.

To overcome this limitation, the Bound Test was introduced by Pesaran and Shin (1999), and further developed by Shin et al. (2014) for use with the NARDL model. This method offers several advantages: (1) It allows for a mix of I(0) and I(1) variables; (2) It permits different lag lengths across variables; (3) It performs well with small sample sizes; (4) It can estimate long-run relationships even in the presence of endogenous variables (Harris & Sollis, 2003); (5) It requires estimation of only one equation, making the results easier to present and interpret.

Before testing for long-run relationships, this study applies the Bound Test under the NARDL framework, as shown in Equation 3.8.

):

$$\Delta \ln CO2_t = \beta_0 + \underbrace{\sum_{j=1}^{p} \beta_j \Delta \ln CO2_{t-j} + \sum_{i=0}^{q} \delta_{1,i} \Delta \ln GDP_{t-i} + \sum_{i=0}^{q} \delta_{2,i} \Delta \ln GDP^2_{t-i} + \sum_{i=0}^{q} \delta_{3,i} \Delta \ln RR_{t-i} + \sum_{i=0}^{q} \delta_{4,i} \Delta lnFDI^{+}_{t-i} + \sum_{i=0}^{q} \delta_{4,i} \Delta lnFD}_{\text{Short-run}} + \underbrace{\varphi_1 \ln CO2_{t-1} + \varphi_2 \ln GDP_{t-1} + \varphi_3 \ln GDP^2_{t-1} + \varphi_4 \ln RR_{t-1} + \varphi_5^{+} \ln FDI^{+}_{t-1} + \varphi_5^{+} \ln FDI^{-}_{t-1}}_{\text{Long-run}} + \varepsilon_t \quad (Eq. 3.8)$$

The Bound Test mainly relies on the joint F-statistic proposed by Pesaran et al. (2001) or (Narayan, 2017), with the null hypothesis H0: $\varphi_1 = \varphi_2 = \varphi_3 = \varphi_4 = \varphi_5^{+} = \varphi_5^{-} = 0$ against the alternative one: H_1: $\varphi_1 \neq \varphi_2 \neq \varphi_3 \neq \varphi_4 \neq \varphi_5^{+} \neq \varphi_5^{-} \neq 0$. There are two sets of critical values: If the F-value is greater than the upper bound, H_0 is rejected (cointegration exists); If the F-value is below the lower bound, H_0 is accepted (no cointegration); If the F-value falls between the two bounds, the result is inconclusive.

3.1.3. Short-Run Relationship

The short-run relationship is analyzed using the Error Correction Model (ECM), which helps assess how the system adjusts back to long-run equilibrium after cointegration has been confirmed (Ericsson & MacKinnon, 2002; Kremers et al., 1992). In this study, the ECM is presented in Equations 3.9 to 3.12.

$$\Delta \ln CO2_t = \beta_0 + \sum_{j=1}^{p} \beta_j \Delta \ln CO2_{t-j} + \sum_{i=0}^{q} \delta_{1,i} \Delta \ln GDP_{t-i} + \sum_{i=0}^{q} \delta_{2,i} \Delta \ln GDP^2_{t-i} + \sum_{i=0}^{q} \delta_{3,i} \Delta \ln RR_{t-i} + \sum_{i=0}^{q} \delta^{+}_{4,i} \Delta \ln FDI^{+}_{t-i} + \sum_{i=0}^{q} \delta^{-}_{4,i} \Delta \ln FDI^{-}_{t-i} + \varphi_1 \ln CO2_{t-1} + \varphi_2 \ln GDP_{t-1} + \varphi_3 (\ln GDP)^2_{t-1} + \varphi_4 \ln RR_{t-1} + \varphi_5^{+} \ln FDI^{+}_{t-1} + \varphi_5^{-} \ln FDI^{-}_{t-1} + \varepsilon_t \quad (Eq. 3.9)$$

$$\Delta \ln CO2_t = \beta_0 + \sum_{j=1}^{p} \beta_j \Delta \ln CO2_{t-j} + \sum_{i=0}^{q} \delta_{1,i} \Delta \ln GDP_{t-i} + \sum_{i=0}^{q} \delta_{2,i} \Delta \ln GDP^2_{t-i} + \sum_{i=0}^{q} \delta_{3,i} \Delta \ln RR_{t-i} + \sum_{i=0}^{q} \delta^{+}_{4,i} \Delta \ln FDI^{+}_{t-i} + \sum_{i=0}^{q} \delta^{-}_{4,i} \Delta \ln FDI^{-}_{t-i} + \alpha_5 u_{t-1} + v_t \quad (Eq. 3.10)$$

$$\Delta \ln CO2_t = \beta_0 + \sum_{j=1}^{p} \beta_j \Delta \ln CO2_{t-j} + \sum_{i=0}^{q} \delta_{1,i} \Delta \ln GDP_{t-i} + \sum_{i=0}^{q} \delta_{2,i} \Delta \ln GDP^2_{t-i} + \sum_{i=0}^{q} \delta_{3,i} \Delta \ln RR_{t-i} + \sum_{i=0}^{q} \delta^{+}_{4,i} \Delta \ln FDI^{+}_{t-i} + \sum_{i=0}^{q} \delta^{-}_{4,i} \Delta \ln FDI^{-}_{t-i} + \theta ECT_{t-1} + v_t \quad (Eq. 3.11)$$

Where, ECT_{t-1} is the error correction term, which reflects how the system adjusts back to long-run equilibrium after a short-term shock. Or, θ indicates whether this adjustment is fast or slow.

$$ECT_{t-1} = \Delta \ln CO2_t - \beta_0 - \sum_{j=1}^{p} \beta_j \Delta \ln CO2_{t-j} - \sum_{i=0}^{q} \delta_{1,i} \Delta \ln GDP_{t-i} - \sum_{i=0}^{q} \delta_{2,i} \Delta \ln GDP^2_{t-i} - \sum_{i=0}^{q} \delta_{3,i} \Delta \ln RR_{t-i} - \sum_{i=0}^{q} \delta^{+}_{4,i} \Delta \ln FDI^{+}_{t-i} - \sum_{i=0}^{q} \delta^{-}_{4,i} \Delta \ln FDI^{-}_{t-i} - v_t \quad (Eq. 3.12)$$

In the NARDL model, lagged level variables are included similarly to ECM, but without coefficient restrictions, making NARDL a more general form of the ECM. If the error correction term equals zero, the system is in equilibrium. If it is not zero, the variables will gradually adjust to return to a stable state. For example, if CO_2 emissions exceed the equilibrium level, the model predicts a decrease in the next period to correct the imbalance. The ECM shows how fast the system returns to equilibrium, and it can be estimated using OLS since it relies on stationary series.

3.1.4. Long-Run Relationship

In the NARDL model, parameters β_i; δ_i represent short-term dynamic relationships, while φ_i represent the long-run dynamic relationship. To analyze nonlinearity, this study applies the asymmetric ARDL approach by Shin et al. (2014). Specifically, the variable lnFDI is split into two parts: $lnFDI^+$ (positive changes) and $lnFDI^-$ (negative changes), to assess the different impacts of FDI on CO_2 emission intensity. The long-run model is shown in Equation 3.13:

$$\Delta lnCO2_t = \varphi_1 lnCO2_{t-1} + \varphi_2 lnGDP_{t-1} + \varphi_3 lnGDP^2_{t-1} + \varphi_4 lnRR_{t-1} + \varphi_5^+ lnFDI^+_{t-1} + \varphi_5^- lnFDI^-_{t-1} + \varepsilon_t \quad (Eq. 3.13)$$

This model helps compare the effects of increases and decreases in FDI, providing a basis for policy recommendations on resource use and technological innovation in production.

3.2. Quantile-on-Quantile Regression Method

Quantile-on-Quantile Regression (QQR) is an extension of the traditional quantile regression method, allowing for a deeper analysis of nonlinear and heterogeneous relationships. While traditional quantile regression examines how the independent variable affects different quantiles of the dependent variable, QQR analyzes this relationship across the quantiles of both the dependent and independent variables at the same time.

The relationship between the dependent variable y_t (CO_2 emission intensity) and the independent variable x_t (GDP, RR and FDI) through QQR provides a deeper understanding of how different levels of the independent variable affect the dependent variable—something that traditional quantile regression often overlooks, as noted by (Sim & Zhou, 2015) and (Ding et al., 2022). The general model is: $y_t = \beta^0(x_t) + \varepsilon_t^\theta$

Now let τ - quantile of x_t be x_t^τ, the relationship above be approximated by first order Taylor expansion of $\beta^0(x_t)$ around

$$y_t = \beta_1(\tau,\theta) + \beta_2(\tau,\theta)(x_t - x_t^0) + \varepsilon_t^\theta$$

The model is estimated using kernel-weighted quantile regression, which focuses on analyzing the local impact at each quantile τ. The weighting function $K(\cdot)$ s inversely related to the distance between x_t and x_t^τ, with the bandwidth h selected based on (Silverman, 1986) formula to determine the influence range of data points near the quantile being analyzed. The constant α is chosen based on the normal distribution to ensure the accuracy and stability of the kernel estimation.

$$\hat{\beta}(\tau,\theta) = \underset{\beta(\tau,\theta)}{\operatorname{agrmin}} \sum_{t=1}^{T} \rho_\theta \left(y_t - \beta_1(\tau,\theta) - \beta_2(\tau,\theta)(x_t - x_t^\tau) \right) K\left(\frac{(x_t - x_t^\tau)}{h} \right)$$

$$h = 0.9. \min\left(\sigma, \frac{IQR}{1.34}\right). n^{\frac{-1}{5}}$$

Where: σ is the sample standard deviation, IQR is the interquartile range of the data, and n is the number of observations.

The standard normal kernel function is expressed as:

$$K(u) = \frac{1}{\sqrt{2\pi}} \exp\left(-\frac{u^2}{2}\right)$$

Where: $u = \frac{x_t - x_t^\theta}{h}$ is the standardized deviation between the observed value and the quantile being analyzed, with h representing the bandwidth.

In addition to the standard normal kernel, this study also considers the Epanechnikov kernel, which is another commonly used kernel in nonparametric analysis due to its theoretical optimality in certain cases (Epanechnikov, 1969). The Epanechnikov weighting function is defined as:

$$K(u) = \frac{3}{4}\left(1 - u^2\right) \text{ với } |u| \leq 1$$

Compared to the Gaussian kernel, the Epanechnikov kernel has compact support, meaning it assigns weights only within a specific range. This helps improve accuracy in the neighborhood of the quantile being analyzed.

3.3. Data

The study uses annual data from 1987 to 2023, with a total of 36 observations. According to (Tabachnick & Fidell, 2013) and Pham et al. (2022), for time series data, the minimum condition for analysis is that the number of years (*n*) minus the number of independent variables (*k*) must be greater than 20, that is, $(n - k) > 20$. In this study, $(36 - 4) = 32$, so the data meet this requirement.

The dataset in this study includes the following variables: (1) Environmental quality, represented by the CO_2 intensity index (CO_{2i}), which measures annual CO_2 emissions per unit of GDP; (2) Economic growth, measured by GDP per capita at constant 2015 USD; (3) Renewable energy, measured as the percentage of renewable energy in total final energy consumption; (4) Foreign direct investment (FDI), calculated as net inflows of investment from abroad as a percentage of GDP.

The NARDL model is well-suited for small samples, making it appropriate for the 36-year dataset used in this study. It allows for the analysis of the long-run relationship between CO_2 emission intensity and key economic factors, while also capturing asymmetric effects when the variables increase or decrease.

Table 2.1: Description of Study Variables

Variable	Unit measurement	Period	Data source
CO_{2i}	Carbon intensity of GDP (kg CO_{2e} per constant 2015 US$ of GDP)	Annual data, from 1987 to 2023	World Bank Indicators, 2025
GDP	USD per capita, constant 2015, US$	Annual data, from 1987 to 2023	World Bank Indicators, 2025
RR	Renewable energy consumption (% of total final energy consumption)	Annual data, from 1990 to 2021	World Bank Indicators, 2025
FDI	Foreign direct investment, net inflows (% of GDP)	Annual data, from 1987 to 2023	World Bank Indicators, 2025

Table 2.2 presents the descriptive statistics of the variables used in the study. Since the variables have different units of measurement, they are converted into logarithmic form before being used in the NARDL model, as shown in Equation (3.2).

Table 2.2: Descriptive Statistics of the Variables

Indicator	**CO2** (kg CO_{2e} per constant 2015 US$ of GDP)	**GDP** (GDP per Capita, US$, constant 2015)	**RR** (% of total final energy consumption)	**FDI** (NetFlow FDI, % of GDP)
Mean	0.72	1790.71	46.67	4.98
Median	0.76	1609.96	44.15	4.36
Standard Deviation	0.19	948.69	17.12	2.55
Kurtosis	-0.85	-0.85	-1.09	1.10
Skewness	0.13	0.56	0.16	0.54
Minimum	0.42	616.72	18.90	0.03
Maximum	1.09	3760.40	75.90	11.94
Observations	37	37	32	37

4. RESULTS

4.1. Test for Data Stationarity and Cointegration

This study applies both the ADF and PP tests to examine the stationarity of the time series. The results, presented in Table 3.1, show that the variable lnGDP is stationary at level in some models (I(0)), while $lnCO_{2i}$, lnGDP, lnRR and lnFDI are only stationary after first differencing, meaning they are integrated of order one (I(1)). Therefore, all series meet the requirement of being either I(0) or I(1), which satisfies the basic condition for applying the ARDL model in the subsequent analysis.

Table 4.1: Unit root tests

Null Hypothesis: The variable has a unit root

Variable	Model	ADF		PP		Order of stationary with constant
		Level	First Difference	Level	First Difference	
$lnCO_{2i}$	Constant	-0.2849^{ns}	-4.2505^{***}	-0.4564^{ns}	-4.0425^{***}	I(1)
	Trend	-3.6744^{**}	-4.2404^{**}	-3.6624^{**}	-4.0582^{**}	
	None	-0.9998^{ns}	-4.1567^{***}	-1.0049^{ns}	-4.0778^{***}	
lnGDP	Constant	-3.7420^{***}	-3.1656^{**}	-0.7640^{ns}	-4.2488^{***}	I(0), I(1)
	Trend	-1.9446^{ns}	-5.5837^{***}	-1.5997^{ns}	-4.3615^{***}	
	None	19.8819^{ns}	-0.3102^{ns}	14.9934^{ns}	-0.4858^{ns}	
lnRR	Constant	-0.4927^{ns}	-5.1535^{***}	-0.1003^{ns}	-2.7521^{*}	I(1)
	Trend	-4.1494^{**}	-3.7246^{**}	-2.8576^{ns}	-1.3672^{ns}	
	None	-2.5047^{**}	-3.4274^{***}	-7.1959^{***}	-3.2668^{*}	
lnFDI	Constant	-6.0782^{***}	-4.4428^{***}	-4.73741^{***}	-4.44791^{***}	I(0), I(1)
	Trend	-5.5394^{***}	-4.9187^{***}	-4.41288^{***}	-4.93026^{***}	
	None	-1.8577^{*}	-4.3609^{***}	-1.97041^{**}	-4.35871^{***}	

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

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

Before analyzing the long-run relationship, the study conducts the Bound Test. The results (Table 4.2) show that the F-value exceeds the upper critical bound at the 1% significance level, indicating that there is a long-run relationship between CO_2 emission intensity and economic growth, renewable energy, and FDI.

Table 4.2: NARDL Bound Test estimation

Null Hypothesis: No levels relationship

F-statistic	F-bounds test statistics		
	Significance	**I(0)**	**I(1)**
8.6219	10%	2.26	3.35
	5%	2.62	3.79
	1%	3.41	4.68

The results in Table 4.3 show that the symmetry hypothesis for the FDI coefficient is rejected at a significance level close to 10% (p-value = 0.0955 based on the Chi-square test). This suggests that the impact of FDI on environmental quality may be asymmetric. Therefore, separating FDI into positive and negative changes in the model is appropriate to reflect this characteristic.

Table 4.3: Coefficient symmetry tests

Null hypothesis: Coefficient is symmetric			
Degrees of freedom: F(1,21), Chi-square(1)			
Variable	**Statistic**	**Value**	**Probability**
Long-run			
lnFDI	F-statistic	2.7798	0.1103
	Chi-square	2.7798	0.0955

4.2. Short-Run and Long-Run Relationships

The Bound Test confirms the existence of a long-run relationship among the variables. According to the NARDL model (Table 4.4), a 1% increase in GDP leads to a 7.08% increase in CO_2 emission intensity, indicating a negative environmental effect of economic growth (statistically significant at the 1% level). The error correction term (ECT) is −0.6748 and significant at the 1% level, showing that the system has the ability to return to long-run equilibrium—that is, CO_2 emission intensity tends to decline as the economy continues to grow.

Table 4.4: Estimation Results from the NARDL Model

Variable	Coefficient	Std. Error	Prob.
Analysis of Short-Run Relationship			
CO_2INTENSITY(-1)*	-0.6748	0.1279	0.0000
GDP(-1)	4.7808	0.8931	0.0000
GDP^2(-1)	-0.3223	0.0578	0.0000
RR**	-0.6759	0.1184	0.0000
@CUMDP(FDI)**	-0.0464	0.0271	0.1011
@CUMDN(FDI)	0.0455	0.0448	0.3214
D(GDP)	-7.0928	6.0712	0.2558
D(GDP(-1))	20.4690	7.2851	0.0105
D(GDP^2)	0.4669	0.4125	0.2704
D(GDP^2(-1)	-1.4700	0.5087	0.0088
C	-14.9459	3.1902	0.0001
R-squared	0.7895	F-statistic	
Adjusted R-squared	0.6892	Probability (F-statistic)	
Analysis of Long-Run Relationship			
lnGDP(-1)	7.0851^{***}	1.0351	0.0000
$(\ln GDP)^2$	-0.4777^{***}	0.0717	0.0000
lnRR	-1.0017^{***}	0.1924	0.0000
$\ln FDI^+(-1)$	-0.0688^{**}	0.0352	0.0608
$\ln FDI^-(-1)$	0.0674^{ns}	0.0680	0.3308
Diagnostic tests			
Tests	F-Statistic	Prob. F	
Breusch-Godfrey Serial Correlation LM test	0.0916ns	0.9129	
Breusch-Pagan-Godfrey Heteroscedasticity test	1.5446ns	0.1924	

Note: D is the difference operator
(*)Significant at the 10%; (**)Significant at the 5%; (***) Significant at the 1% and (ns) Not Significant
Breusch-Godfrey LM Serial Correlation test; Breusch-PaganGodfrey Heteroscedasticity test; Cumulative Sum (CUSUM) stability test; Cumulative Sum of Square (CUSUM-Sq.) stability test.

In addition, a 1% increase in renewable energy leads to a 1% reduction in CO_2 emission intensity (significant at the 1% level), highlighting the positive role of clean energy sources. Meanwhile, a 1% increase in FDI contributes to a slight decrease in CO_2 intensity by about 0.07% (significant at the 10% level), whereas a decrease in FDI has no significant effect.

Figure 4.1 clearly illustrates the difference between the impact of rising FDI (FDI^+) and falling FDI (FDI^-), with the effect confirmed as statistically significant within the 95% confidence interval—supporting the asymmetric influence of FDI on CO_2 emission intensity.

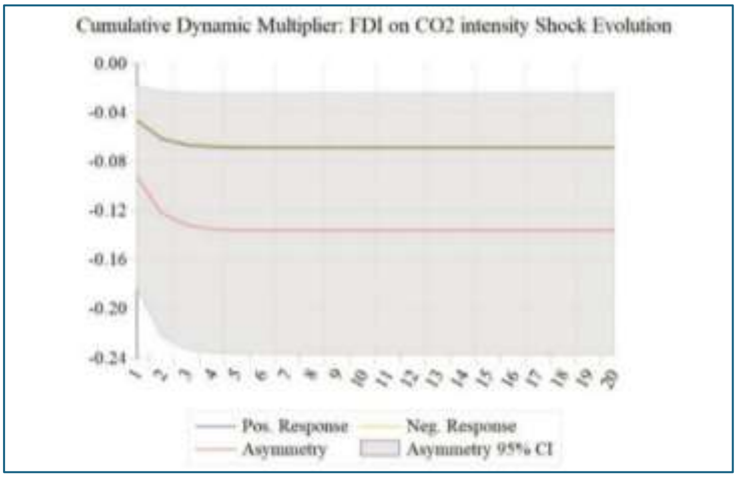

Figure 4.1: Non-linear ARDL dynamic multiplier effect graphs

Regarding model diagnostics, Table 4.4 shows that the NARDL model does not suffer from problems of misspecification, autocorrelation, or heteroskedasticity. Figure 4.2 presents the results of the CUSUM and CUSUMQ tests, where the test lines remain within the 5% confidence bands, indicating that the model is stable.

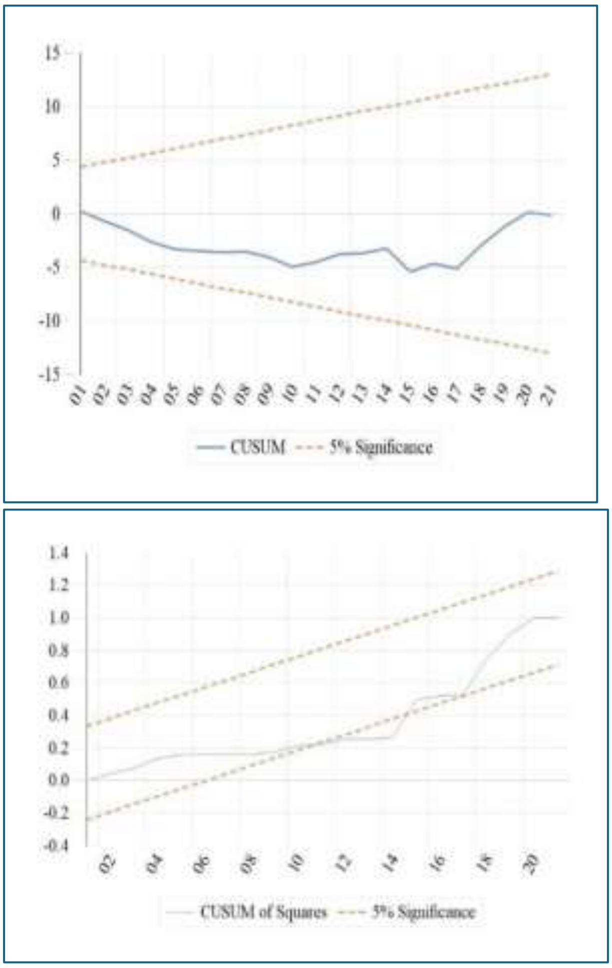

Figure 4.2: Non-linear ARDL CUSUM and CUSUMSQ graphs

5. DISCUSSION

5.1. Economic growth and the environmental kuznets curve hypothesis in Vietnam

From 1987 to 2023, Vietnam's GDP per capita rose steadily from under USD 500 to nearly USD 3,800. Despite fluctuations, growth remained strong, driving industrialization and posing major environmental challenges (Figure 5.1).

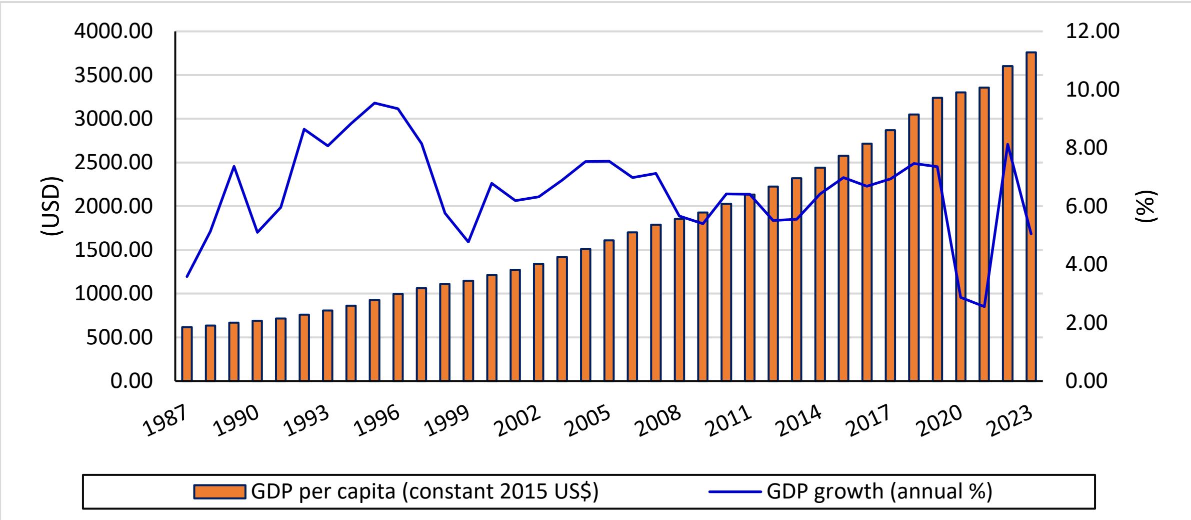

Figure 5.1: Economic growth and per capita GDP in Vietnam from 1987 to 2023

Results from the NARDL model indicate that GDP has a positive long-run coefficient (2.7381, $p < 0.01$), while GDP^2 is negative (−0.1261, $p < 0.01$), both statistically significant. This provides strong evidence of a nonlinear relationship between economic growth and CO_2 emission intensity in Vietnam, consistent with the Environmental Kuznets Curve (EKC). In the early phase of development, GDP growth is associated with rising emissions due to industrial expansion and dependence on fossil fuels. However, beyond a certain income threshold, emissions begin to decline, reflecting the effects of economic restructuring, technological progress, and stricter environmental regulations.

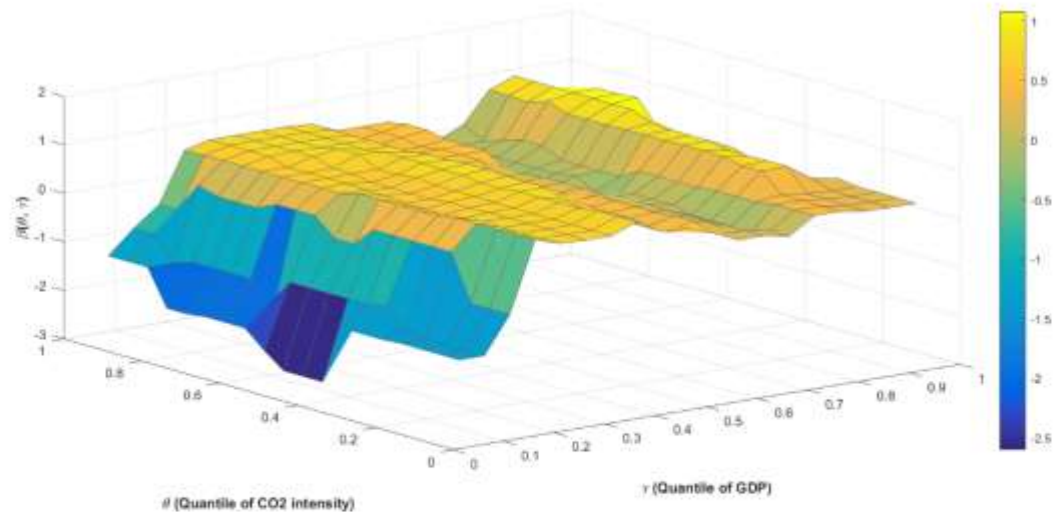

Figure 5.2a: QQR results between GDP and CO_2 intensity using the Epanechnikov kernel in Vietnam (1987–2023)

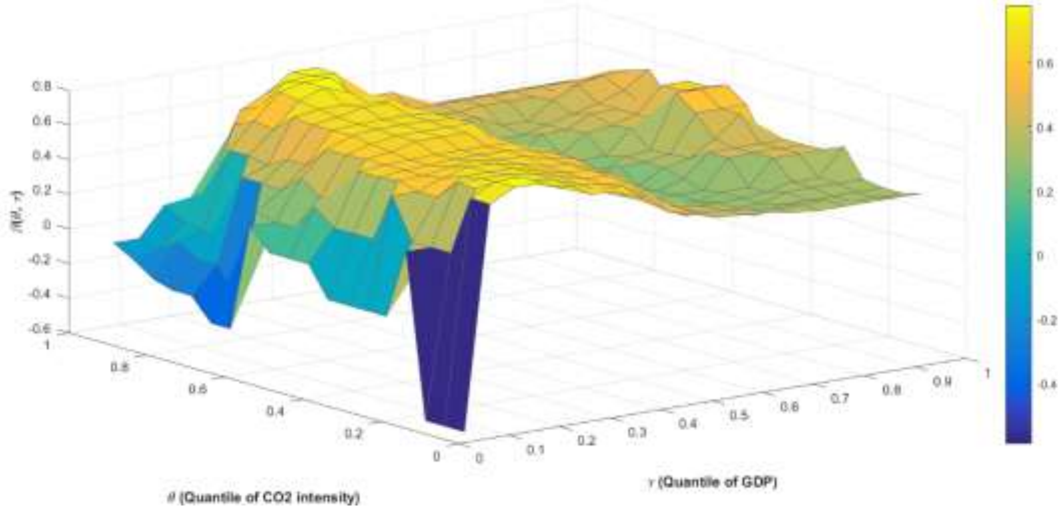

Figure 5.2b: QQR results between GDP and CO_2 intensity using the Gaussian kernel in Vietnam (1987–2023)

QQR results reveal a nonlinear and asymmetric relationship between GDP and CO_2 intensity in Vietnam, with an inverted U-shape pattern appearing at medium to high GDP quantiles—supporting the EKC hypothesis. These findings reinforce the NARDL results and show that while NARDL captures average effects, QQR identifies turning points across development stages, clarifying when and under what conditions CO_2 intensity begins to decline. This highlights the need for tailored green growth policies at each phase of economic development. The NARDL results of this study confirm the existence of the Environmental Kuznets Curve (EKC) hypothesis for the relationship between CO_2 emissions and GDP in Vietnam. This finding aligns with previous panel-data studies on Asian countries, including Vietnam, which also identified an inverted U-shaped EKC pattern (Bilgili et al., 2023; Nguyen et al., 2024). Similarly, Azam et al. (2024) support the EKC's presence across many middle-income countries—a group to which Vietnam belongs. However, our results contrast with Tran et al. (2023), who used an ARDL model and found no evidence of the EKC between GDP and coal consumption in Vietnam, reporting only an upward trend. This difference may from the use of different environmental indicators (CO_2 vs. coal) or the composition of variables in the models. Moreover, institutional factors such as government effectiveness have also been shown to play a significant role in shaping the EKC, as noted by Al-Mulali et al. (2022). Overall, this study strengthens the empirical support for the EKC in the context of Vietnam's economic growth.

5.2. The role of renewable energy in improving environmental quality

The chart for the period 1990–2022 shows a sharp decline in the share of renewable energy, while CO_2 emission intensity per USD of GDP nearly doubled. This trend highlights the essential role of renewable energy in controlling emissions and promoting sustainable development (Figure 5.3).

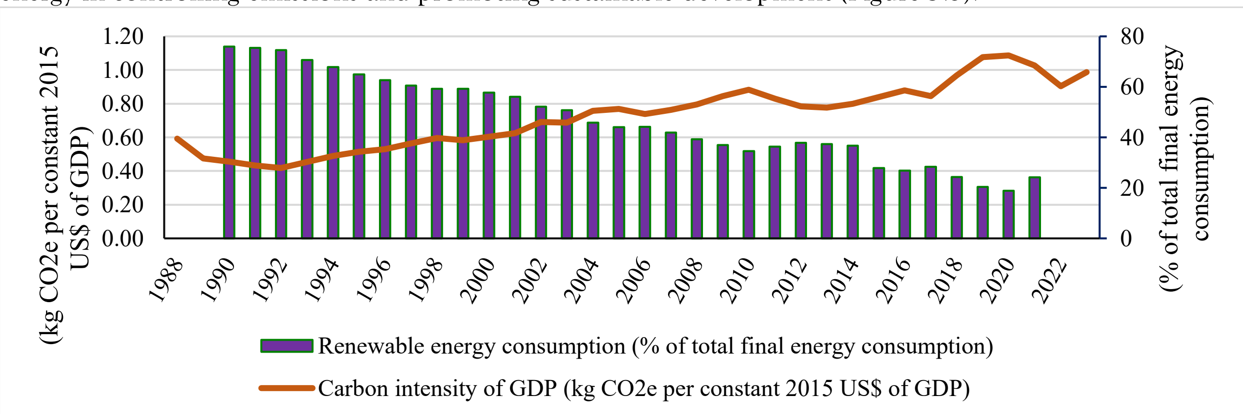

Figure 5.3: Trends in renewable energy consumption and CO_2 intensity in Vietnam

(1987–2023)
Estimation results from the NARDL model show that renewable energy has a negative and statistically significant effect on CO_2 emission intensity in both the short and long run. Specifically, the short-run coefficient is -0.6759 ($p < 0.01$), and the long-run coefficient is -1.0017 ($p < 0.01$). These findings confirm that increasing the share of renewable energy in the overall energy mix significantly contributes to reducing CO_2 emissions per unit of GDP.

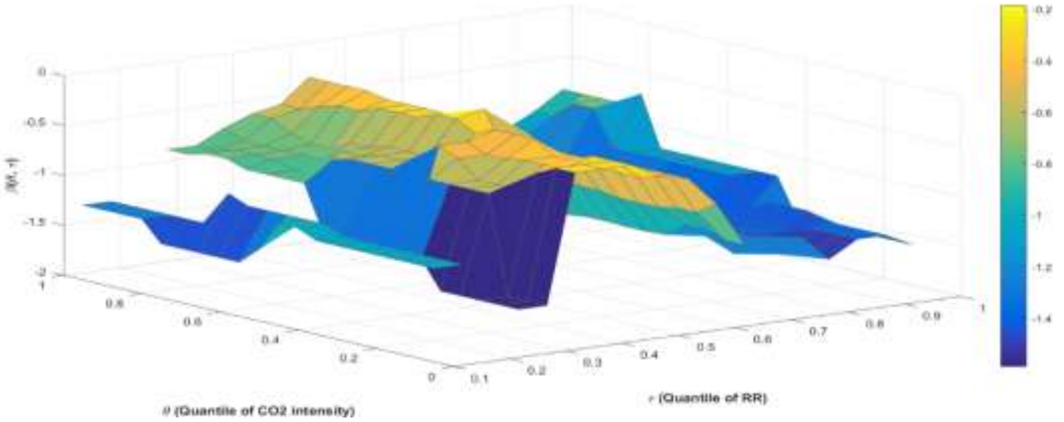

Figure 5.4a: Quantile-on-Quantile relationship between renewable energy consumption and CO_2 intensity using the Epanechnikov Kernel in Vietnam (1987–2023)

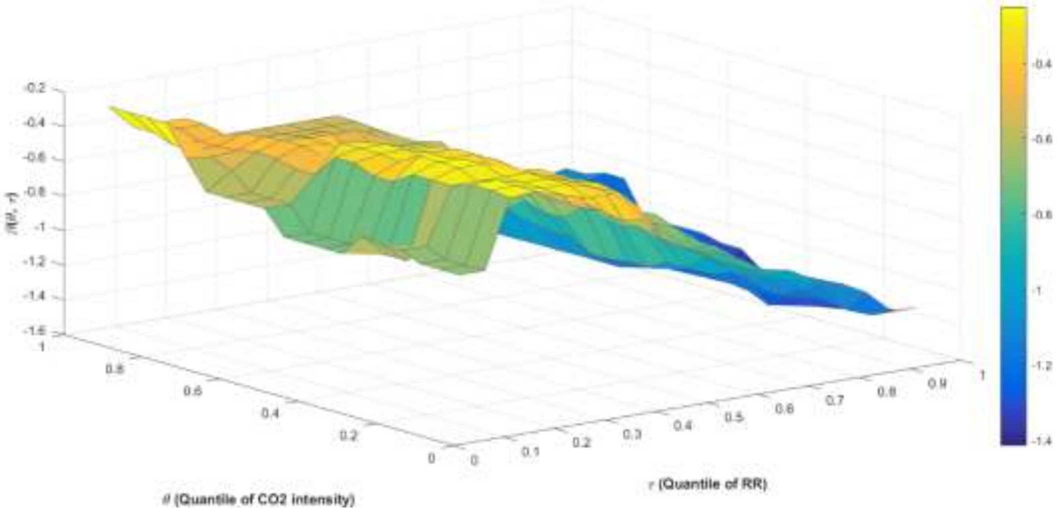

Figure 5.4b: Quantile-on-Quantile relationship between renewable energy consumption and CO_2 intensity using the Gaussian Kernel in Vietnam (1987–2023)

For renewable energy, QQR provides strong and consistent evidence of an inverse relationship with CO_2 intensity across all quantiles. Both Gaussian and Epanechnikov kernels show mostly negative coefficients, especially at high CO_2 quantiles and medium–high quantiles of renewable energy. This not only supports the NARDL results—where the long-run coefficient of RR is negative and significant—but also highlights the stability and broad relevance of this effect. While NARDL reflects average impacts, QQR reveals that the strongest emission-reducing effects occur during high-emission phases when renewable energy use is high. These findings reinforce the urgency of scaling up renewable energy policies in Vietnam. This study, using NARDL and QQR models, shows that increasing the use of renewable energy helps reduce CO_2 emissions in Vietnam. This finding supports and aligns with many recent studies on environmental sustainability in the country. Awosusi et al. (2023) using a dynamic ARDL model, also found that RR helps lower environmental damage (measured by CO_2). Similarly, Nam et al. (2024) using an asymmetric ARDL model, showed that higher RR use reduces the ecological footprint—a measure of pressure on natural resources closely related to CO_2 emissions—especially in the long run. Although other studies, such as Nguyen et al. (2024) focus on financial globalization, and Behera et al. (2024) examine changes in GDP, both still support the role of RR by recommending clean energy and green technologies as part of sustainable growth. Ha et al. (2023) while focusing on how global economic changes affect energy use, also emphasized the need to understand the role of different energy sources in Vietnam. Overall, the findings of this study fit well with recent research and confirm that switching to renewable energy is a key step for Vietnam to cut carbon emissions.

5.3. The asymmetric impact of foreign direct investment on CO_2 emission intensity

The chart shows that while FDI (as a percentage of GDP) has increased sharply since the mid-1990s, CO_2 emission intensity also began to rise again and remained high from 2005 onward. This suggests that although FDI supports economic growth, it has not been effective in helping reduce emissions—and may even contribute to higher CO_2 intensity.

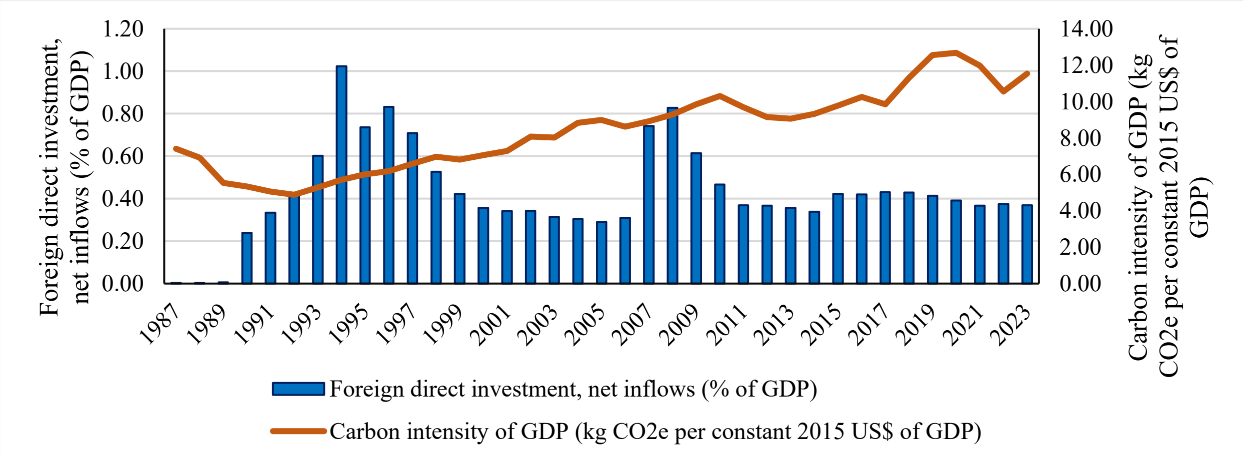

Figure 5.5: Trends in FDI net inflows and CO_2 intensity in Vietnam (1987–2023)

NARDL results reveal an asymmetric effect of FDI on CO_2 intensity in Vietnam. In the long run, positive FDI (FDI^+) significantly reduces emissions (−0.0688, p = 0.0608), while negative FDI (FDI^-) shows no significant impact (0.0674, p = 0.3308), highlighting the importance of promoting green-oriented FDI. Compared to NARDL, the QQR approach offers deeper insights across quantiles. It shows that FDI's emission-reducing effect is strongest at low to mid quantiles of both CO_2 intensity and FDI, but fades at higher quantiles—suggesting that even high-quality FDI only benefits the environment under certain economic and emission conditions. Together, these findings underscore the need for targeted green FDI policies tailored to Vietnam's specific development context.

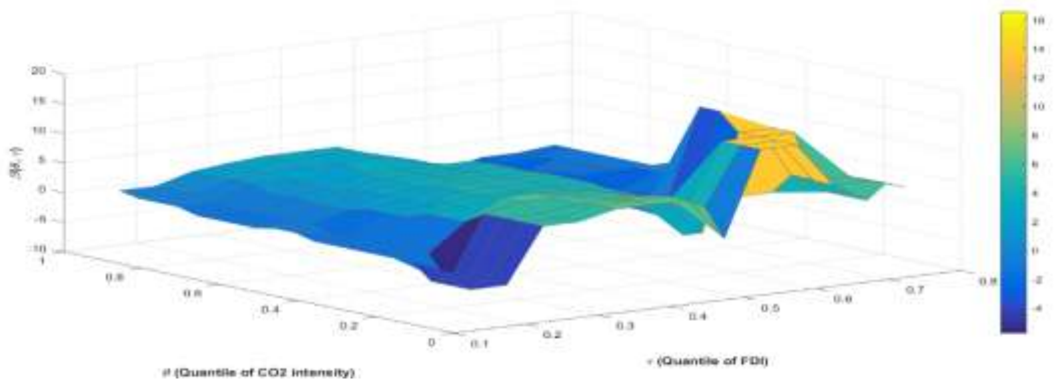

Figure 5.6a: Quantile-on-Quantile relationship between FDI and CO_2 intensity using the Epanechnikov Kernel in Vietnam (1987–2023)

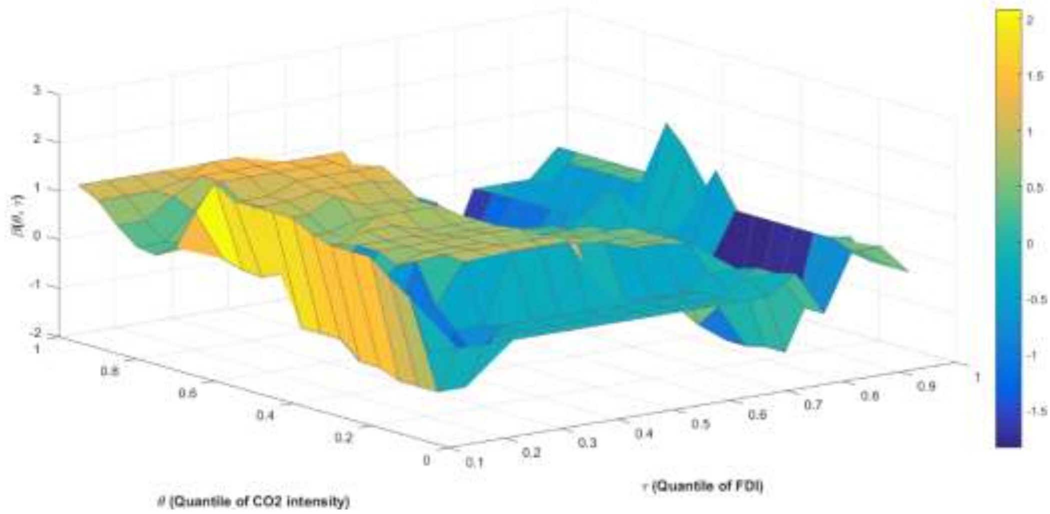

Figure 5.6b: Quantile-on-Quantile relationship between FDI and CO_2 intensity using the Gaussian Kernel in Vietnam (1987–2023)

NARDL results for Vietnam show that increasing FDI (FDI^+) significantly reduces CO_2 emissions, supporting the "pollution halo" hypothesis. This finding is consistent with (Bello et al., 2024) who reported a similar positive environmental effect of FDI in ASEAN countries. However, the result contrasts with Soukaina and Kammoun (2024) who found that FDI increases CO_2 emissions in 19 Asian countries (grouped by income level), especially in middle- and high-income economies—supporting the "pollution haven" hypothesis. Likewise, (Ketchoua et al., 2024) observed that FDI hinders green growth in OECD countries by increasing emissions. (Mehmood, 2022) in a study of South Asia, highlighted the importance of governance and renewable energy in making FDI more environmentally friendly. The findings of this study generally support the "pollution halo" hypothesis, especially as Vietnam gradually improves environmental standards in FDI attraction. The increase in FDI can enhance environmental quality by introducing cleaner technologies and higher production standards from international investors. However, such benefits depend on clear screening mechanisms regarding investment goals, technical capacity, and environmental commitments from foreign firms—areas in which Vietnam is still making progress.

6. Conclusion and Policy Implications

This study examines the link between economic growth and environmental quality in Vietnam using two advanced methods: the nonlinear NARDL model and Quantile-on-Quantile Regression (QQR). CO_2 emission intensity (emissions per unit of GDP) is used as the main environmental indicator, while key factors include GDP (log), GDP^2 (to test EKC), renewable energy, and FDI (split into positive and negative flows in NARDL). The results confirm a nonlinear EKC pattern between GDP and CO_2 intensity, supported by both NARDL and QQR. Renewable energy and FDI show asymmetric effects across quantiles, suggesting that policy impacts vary by context. However, the EKC outcome depends on variable choice—different environmental or economic indicators may lead to different conclusions. Thus, findings should be interpreted within the scope of the variables used.

Based on the quantitative findings, this study suggests three key policy directions to promote green growth and improve environmental control in Vietnam.

First, renewable energy should be scaled up in both quantity and quality, as it significantly reduces CO_2 intensity—especially at higher quantiles. However, this effect becomes clear only when renewable energy reaches a certain scale and is supported by adequate infrastructure. Vietnam has issued several important policies, including the National Energy Development Strategy (Decision No. 1855/QĐ-TTg, 2007), the Renewable Energy Development Strategy to 2030 (Decision No. 2068/QĐ-TTg), and the Power Development Plan VIII (Decision No. 500/QĐ-TTg, 2023). These all aim to increase the share of renewables in the energy mix. Still, challenges remain, such as FIT pricing, transmission/storage bottlenecks, and lack of incentives for advanced technology. Solutions include better financial support, streamlined project approvals, and competitive electricity markets to fully unlock renewable potential.

Second, FDI policy needs to be reoriented toward quality and sustainability. The study shows FDI has mixed impacts: in some quantiles, it helps reduce emissions via green technology; in others, it increases CO_2 intensity due to polluting industries. To address this, Vietnam should implement Resolution No. 50-NQ/TW (2019) by setting mandatory environmental criteria for FDI approval, linking incentives to emissions, technology transfer, and ESG disclosure, and developing tools like carbon credits to distinguish sustainable FDI. Enforcement of the revised Investment Law 2020 (Law No. 61/2020/QH14) should also be strengthened, particularly in monitoring post-investment environmental performance.

Third, since Vietnam has not yet reached the EKC "turning point"—where economic growth leads to lower emissions—its growth model should shift from extensive to intensive, prioritizing quality and green innovation. The National Green Growth Strategy 2021–2030 (Decision No. 1658/QĐ-TTg) and the 2020 Environmental Protection Law provide a roadmap for this transition. To meet the net-zero target by 2050 (COP26), economic, environmental, energy, and investment policies must be aligned, with stronger quantitative evaluation of their real-world impacts.

In summary, this study provides empirical support for the EKC in Vietnam and highlights the asymmetric and context-specific roles of renewable energy and FDI in shaping the growth–emissions link. The proposed policy directions are grounded in both data and Vietnam's legal framework, aiming toward a greener, more resilient economy. Future studies should expand to ASEAN or global levels, and include variables such as institutional quality, ESG scores, or technological capacity to better understand how policies shape the global energy transition.

Tài liệu tham khảo

1. Abid, L., Kacem, S., & Saadaoui, H. (2024). Addressing the Environmental Kuznets Curve in the West African Countries: Exploring the Roles of FDI, Corruption, and Renewable Energy. *Journal of the Knowledge Economy*, *15*(4), 20491-20515. https://doi.org/10.1007/s13132-024-01858-4

2. Akhtar, M. Z., Zaman, K., & Khan, M. A. (2024). Governance, foreign investment, and growth: the impact of governance indicators, foreign direct investment, economic expansion, and industrialization on carbon emissions. *SN Business & Economics*, *4*(12), 148. https://doi.org/10.1007/s43546-024-00743-1

3. Al-Mulali, U., Gholipour, H. F., & Solarin, S. A. (2022). Investigating the environmental Kuznets curve (EKC) hypothesis: does government effectiveness matter? Evidence from 170 countries. *Environment, Development and Sustainability*, *24*(11), 12740-12755. https://doi.org/10.1007/s10668-021-01962-4

4. Asongu, S., El Montasser, G., & Toumi, H. (2016). Testing the relationships between energy consumption, CO2 emissions, and economic growth in 24 African countries: a panel ARDL approach. *Environmental Science and Pollution Research*, *23*(7), 6563-6573. https://doi.org/10.1007/s11356-015-5883-7

5. Awosusi, A. A., Ozdeser, H., Ojekemi, O. S., Adeshola, I., & Ramzan, M. (2023). Environmental sustainability in Vietnam: evaluating the criticality of economic globalisation, renewable energy, and natural resources. *Environmental Science and Pollution Research*, *30*(30), 75581-75594. https://doi.org/10.1007/s11356-023-27683-x

6. Ayık, U., & Özer, H. (2025). Comparative analysis of the environmental Kuznets curve hypothesis for E7 countries on the relationship between CO2 emissions and economic growth. *Environment, Development and Sustainability*. https://doi.org/10.1007/s10668-025-06131-5

7. Azam, M., Rehman, Z. U., Khan, H., & Haouas, I. (2024). Empirical testing of the environmental Kuznets curve: evidence from 182 countries of the world. *Environment, Development and Sustainability*. https://doi.org/10.1007/s10668-024-04890-1

8. Baigorri, B., Montañés, A., & Simón-Fernández, M.-B. (2025). The influence of the Great Recession on the relationship between ecological footprint, renewable energy and economic growth. *Environmental and Sustainability Indicators*, *25*, 100556. https://doi.org/10.1016/j.indic.2024.100556

9. Behera, C., Mohanty, R. K., Priyadarsini, B. T., & Patnaik, D. (2024). Nexus between CO2 emission, renewable energy, trade openness and foreign direct investment, and output volatility. *Economic Change and Restructuring*, *57*(5), 155. https://doi.org/10.1007/s10644-024-09736-4

10. Bekun, F. V., Gyamfi, B. A., Olasehinde-Williams, G., & Yadav, A. (2024). Revisiting the Foreign Direct Investment-CO2 Emissions Nexus within the N-EKC Framework: Evidence from South Asian Countries. *Sustainable Futures*, *8*, 100357. https://doi.org/10.1016/j.sftr.2024.100357

11. Bello, M. O., Jimoh, S. O., Ch'ng, K. S., & Oyerinola, D. S. (2024). Environmental sustainability in ASEAN: what roles do energy consumption, economic growth, and foreign direct investment play? *Environment, Development and Sustainability*. https://doi.org/10.1007/s10668-024-05250-9

12. Bilgili, F., Khan, M., & Awan, A. (2023). Is there a gender dimension of the environmental Kuznets curve? Evidence from Asian countries. *Environment, Development and Sustainability*, *25*(3), 2387-2418. https://doi.org/10.1007/s10668-022-02139-3

13. Bui Minh, T., Nguyen Ngoc, T., & Bui Van, H. (2023). Relationship between carbon emissions, economic growth, renewable energy consumption, foreign direct investment, and urban population in Vietnam. *Heliyon*, *9*(6), e17544. https://doi.org/10.1016/j.heliyon.2023.e17544

14. Byaro, M., Rwezaula, A., & Mafwolo, G. (2024). Does institutional quality play a role in mitigating the impact of economic growth, population growth and renewable energy use on environmental sustainability in Asia? *Environment, Development and Sustainability*. https://doi.org/10.1007/s10668-024-04780-6

15. Chen, Q., & Wang, J. (2025). The impact of digital economic growth and financial expansion on CO2 mitigation strategies in leading emitting countries. *Scientific Reports*, *15*(1), 10515. https://doi.org/10.1038/s41598-025-86412-1

16. Dickey, D. A., & Fuller, W. A. (1979). Distribution of the Estimators for Autoregressive Time Series with a Unit Root. *Journal of the American Statistical Association*, *74*(366a), 427-431. https://doi.org/10.1080/01621459.1979.10482531

17. Ding, Y., Liu, Y., & Failler, P. (2022). The Impact of Uncertainties on Crude Oil Prices: Based on a Quantile-on-Quantile Method. *Energies*, *15*(10), 3510. https://doi.org/10.3390/en15103510

18. Dzhumashev, R., & Kazakevitch, G. (2025). Production, Environment, and Population Growth. *Environmental and Resource Economics*. https://doi.org/10.1007/s10640-025-00956-4

19. Engle, R. F., & Granger, C. W. J. (1987). Co-Integration and Error Correction: Representation, Estimation, and Testing. *Econometrica*, *55*(2), 251-276. https://doi.org/10.2307/1913236

20. Environment+Energy Leader. (2024). Vietnam's Strategic Environmental Planning for a Sustainable Future. *Environment+Energy Leader*. https://www.environmentenergyleader.com/stories/vietnams-strategic-environmental-planning-for-a-sustainable-future,44840

21. Epanechnikov, V. A. (1969). Non-Parametric Estimation of a Multivariate Probability Density. *Theory of Probability & Its Applications*, *14*(1), 153-158. 10.1137/1114019

22. Ericsson, N. R., & MacKinnon, J. G. (2002). Distributions of error correction tests for cointegration. *The Econometrics Journal*, *5*(2), 285-318. http://www.jstor.org/stable/23114896

23. Fakhrullah, Xiao, D., Jan, N., Khan, S., & Suplata, M. (2025). Environmental Stewardship and Economic Prosperity: A Comprehensive Assessment of CO2 Emissions and Sustainable Development Goals in European Countries. *Journal of the Knowledge Economy*, *16*(1), 5572-5593. https://doi.org/10.1007/s13132-024-02169-4

24. Freire, F. d. S., da Silva, N. O., & de Oliveira, V. R. F. (2023). Economic growth and greenhouse gases in Brazilian States: is the environmental Kuznets curve applicable hypothesis? *Environmental Science and Pollution Research*, *30*(15), 44928-44942. https://doi.org/10.1007/s11356-023-25411-z

25. Ganda, F., & Panicker, M. (2025). Does access to energy matter? Understanding the complex nexus among energy consumption, ICT, foreign direct investment and economic growth on carbon emissions in Sub-Saharan Africa. *Energy Nexus*, *17*, 100346. https://doi.org/10.1016/j.nexus.2024.100346

26. Grossman, G. M., & Krueger, A. B. (1995). Economic Growth and the Environment*. *The Quarterly Journal of Economics*, *110*(2), 353-377. https://doi.org/10.2307/2118443

27. Guo, J., Zhao, X., & Cheng, H. (2024). Assessing the relationship between foreign direct investment and low carbon development in Chinese manufacturing industry. *International Journal of Environmental Science and Technology*. https://doi.org/10.1007/s13762-024-06221-3

28. Ha, L. T., Hung, N. M., & Van Chon, L. (2023). Decomposed and partial connectedness between economic globalization, non-renewable and renewable energy consumption in Vietnam. *Environmental Science and Pollution Research*, *30*(55), 117061-117081. https://doi.org/10.1007/s11356-023-25158-7

29. Harris, H., & Sollis, R. (2003). *Applied Time Series Modelling and Forecasting*. Wiley

30. Jain, M., Jain, T., & Jain, P. (2023). Revisiting the nexus between economic growth and environment health: an empirical study on 180 nations. *Environmental Science and Pollution Research*, *30*(58), 122550-122579. https://doi.org/10.1007/s11356-023-30585-7

31. Johansen, S. (1988). Statistical analysis of cointegration vectors. *Journal of Economic Dynamics and Control*, *12*(2), 231-254. https://doi.org/10.1016/0165-1889(88)90041-3

32. Ketchoua, G. S., Arogundade, S., & Mduduzi, B. (2024). Revaluating the Sustainable Development Thesis: exploring the moderating influence of Technological Innovation on the impact of Foreign Direct Investment (FDI) on Green Growth in the OECD Countries. *Discover Sustainability*, *5*(1), 252. https://doi.org/10.1007/s43621-024-00433-w

33. Khalid, W., Nawaz, A., Gadou, L. M. A., Khan, S. U., & Aybudak, H. G. (2025). Examining short-run and long-run nexus between economic growth, financial development, energy consumption and environmental degradation: empirical evidence for the Environmental Kuznets Curve Hypothesis in Egypt. *Asia-Pacific Journal of Regional Science*. https://doi.org/10.1007/s41685-025-00371-z

34. Khan, I., Zhong, R., Khan, H., Dong, Y., & Nuţă, F. M. (2024). Examining the relationship between technological innovation, economic growth and carbon dioxide emission: dynamic panel data evidence. *Environment, Development and Sustainability*, 26(7), 18161-18180. https://doi.org/10.1007/s10668-023-03384-w

35. Khan, R. (2024). Catch-up growth with alpha and beta decoupling and their relationships between CO2 emissions by GDP, population, energy production, and consumption. *Heliyon*, *10*(11), e31470. https://doi.org/10.1016/j.heliyon.2024.e31470
36. Khanh Vu, & Phuong Nguyen. (2025). Vietnam's 2024 GDP growth accelerates to 7.09%, driven by strong exports. *Reuters*. https://www.reuters.com/markets/asia/vietnam-2024-gdp-growth-quickens-709-2025-01-06/
37. Kremers, J. J. M., Ericsson, N. R., & Dolado, J. J. (1992). The power of cointegration tests [https://doi.org/10.1111/j.1468-0084.1992.tb00005.x]. *Oxford Bulletin of Economics and Statistics*, *54*(3), 325-348. https://doi.org/10.1111/j.1468-0084.1992.tb00005.x
38. Le Anh. (2025, 2025/05/03). Viet Nam aims to attract high-quality foreign investment. *Nhan Dan Online*. https://en.nhandan.vn/viet-nam-aims-to-attract-high-quality-foreign-investment-post147477.html
39. Leitão, N. C., Dos Santos Parente, C. C., Balsalobre-Lorente, D., & Cantos Cantos, J. M. (2023). Revisiting the effects of energy, population, foreign direct investment, and economic growth in Visegrad countries under the EKC scheme. *Environmental Science and Pollution Research*, *30*(6), 15102-15114. https://doi.org/10.1007/s11356-022-23188-1
40. Li, R., Wang, Q., & Hu, S. (2025). Economic growth without carbon emission: Comparative perspectives on solar, wind, hydroelectric, nuclear, and geothermal energy. *Energy Strategy Reviews*, *59*, 101692. https://doi.org/10.1016/j.esr.2025.101692
41. Maroufi, N., & Hajilary, N. (2022). The impacts of economic growth, foreign direct investments, and gas consumption on the environmental Kuznets curve hypothesis CO2 emission in Iran. *Environmental Science and Pollution Research*, *29*(56), 85350-85363. https://doi.org/10.1007/s11356-022-20794-x
42. Mehmood, U. (2022). Renewable energy and foreign direct investment: does the governance matter for CO2 emissions? Application of CS-ARDL. *Environmental Science and Pollution Research*, *29*(13), 19816-19822. https://doi.org/10.1007/s11356-021-17222-x
43. Nam, L. P., Hang, N. T. B., Van Song, N., & Eluriagac, L. M. T. (2024). Examining the non-linear impact of fossil and renewable energy consumption on Vietnam's ecological footprint: insights from the asymmetric ARDL approach. *Discover Energy*, *4*(1), 10. https://doi.org/10.1007/s43937-024-00034-8
44. Narayan, P. K. (2017). Reformulating Critical Values for the Bounds F- statistics Approach to Cointegration: An Application to the Tourism Demand Model for Fiji. https://doi.org/10.4225/03/5938abda7b4ab
45. Nguyen Si Dung. (2025). A Green Vietnam is a Priceless Heritage. *Nhan Dan Online*. https://en.nhandan.vn/a-green-vietnam-is-a-priceless-heritage-post143781.html
46. Nguyen Thi Nguyet Minh. (2022). Trends and solutions to promote the development of green production in Vietnam. *Tạp chí Công Thương - Các kết quả nghiên cứu khoa học và ứng dụng công nghệ*, *4*. https://tapchicongthuong.vn/xu-huong-va-giai-phap-phat-trien-san-xuat-xanh-tai-viet-nam-88114.htm
47. Nguyen, T. M. H., Nguyen, T. K. L., & Pham, X. T. (2024). Impacts of financial globalization on CO2 emissions in Asian countries and implications for Vietnam. *Asia-Pacific Journal of Regional Science*, *8*(4), 993-1015. https://doi.org/10.1007/s41685-024-00357-3
48. Nsor-Ambala, R., & Amewu, G. (2023). Linear and non-linear ARDL estimation of financial innovation and economic growth in Ghana. *Journal of Business and Socio-economic Development*, *3*(1), 36-49. https://doi.org/10.1108/jbsed-09-2021-0128
49. Nuţă, F. M., Sharafat, A., Abban, O. J., Khan, I., Irfan, M., Nuţă, A. C., Dankyi, A. B., & Asghar, M. (2024). The relationship among urbanization, economic growth, renewable energy consumption, and environmental degradation: A comparative view of European and Asian emerging economies. *Gondwana Research*, *128*, 325-339. https://doi.org/10.1016/j.gr.2023.10.023
50. Odei, S. A., Dunyo, S. K., & Anderson, H. J. (2025). Research and development, economic growth, CO2 emissions and environmental Kuznets curve. *Sustainable Futures*, *9*, 100541. https://doi.org/10.1016/j.sftr.2025.100541
51. Pesaran, M. H., & Shin, Y. (1999). An Autoregressive Distributed-Lag Modelling Approach to Cointegration Analysis. In S. Strøm (Ed.), *Econometrics and Economic Theory in the 20th Century: The Ragnar Frisch Centennial Symposium* (pp. 371-413). Cambridge University Press.https://doi.org/10.1017/CCOL521633230.011
52. Pesaran, M. H., Shin, Y., & Smith, R. J. (2001). Bounds testing approaches to the analysis of level relationships. *Journal of Applied Econometrics*, *16*(3), 289-326. https://doi.org/10.1002/jae.616
53. Peter, C. B. P., & Perron, P. (1988). Testing for a Unit Root in Time Series Regression. *Biometrika*, *75*(2), 335-346. https://doi.org/10.2307/2336182
54. Pham, M. H., Nguyen, A. T., & Le, P. T. (2022). The relationship between ghg emissions and economic growth in Vietnam. *Science & Technology Development Journal - Economics - Law and Management*. https://doi.org/10.32508/stdjelm.v6i1.802
55. Phillips, P. C. B., & Ouliaris, S. (1990). Asymptotic Properties of Residual Based Tests for Cointegration. *Econometrica*, *58*(1), 165-193. https://doi.org/10.2307/2938339
56. Phuong Anh. (2024). A turning point in 35 years of FDI attraction. *Nhan Dan Online*. https://en.nhandan.vn/a-turning-point-in-35-years-of-fdi-attraction-post132507.html
57. Rahman, M. H., Voumik, L. C., Rahman, M. M., & Majumder, S. C. (2024). Scrutinizing the existence of the environmental Kuznets curve in the context of foreign direct investment, trade, and renewable energy in Bangladesh: impending from ARDL method. *Environment, Development and Sustainability*, *26*(5), 12619-12638. https://doi.org/10.1007/s10668-023-03940-4 .