DOI: https://doi.org/10.62985/j.huit_ojs.vol26.no3E.549

THE IMPACT OF OIL CONSUMPTION ON PER CAPITA CO_2 EMISSIONS IN VIETNAM: EVIDENCE FROM AN ARDL MODEL

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Received: 26 March 2026; Revised: 30 April 2026; Accepted: 16 May 2026

ABSTRACT

This study examines the impact of oil consumption on per capita CO_2 emissions in Vietnam using annual time-series data for the period 1990–2024. GDP per capita is included as a control variable to capture the scale effect of economic development on environmental pressure. The paper is grounded in the energy–growth–environment nexus and focuses specifically on oil consumption as a key fossil-energy channel in Vietnam's emissions trajectory. To estimate both long-run and short-run dynamics, the study employs the autoregressive distributed lag (ARDL) approach, which is suitable for small samples and for variables integrated of order zero or one. The empirical results confirm the existence of a stable long-run relationship among per capita CO_2 emissions, oil consumption per capita, and GDP per capita. In the long run, a 1% increase in oil consumption per capita is associated with an approximately 0.451% increase in per capita CO_2 emissions, while a 1% increase in GDP per capita is associated with an approximately 1.034% increase in per capita CO_2 emissions. The error-correction term is negative and statistically significant, indicating relatively rapid adjustment toward long-run equilibrium. Additional checks show that the main findings remain unchanged under an alternative lag-selection criterion, and stability tests provide no evidence of structural instability over the sample period. The findings suggest that Vietnam's emissions trajectory remains closely linked to oil dependence and carbon-intensive growth, underscoring the importance of reducing reliance on oil-based energy use in the transition toward more sustainable development.

Keywords: Oil consumption, CO_2 emissions per capita, GDP per capita, ARDL, Vietnam**.**

1. INTRODUCTION

Climate change has become one of the most pressing development challenges of the twenty-first century. A broad scientific consensus now confirms that fossil-fuel combustion is the dominant driver of the increase in greenhouse gas emissions, with carbon dioxide (CO_2) remaining the principal contributor to anthropogenic warming [1]. Because CO_2 emissions are closely linked to energy use, transport activity, industrial production, and household consumption, the relationship between energy consumption and environmental degradation has become a central issue in environmental economics and sustainable development research [2].

This issue is particularly important for developing and emerging economies, where economic expansion is often accompanied by rising energy demand. Vietnam provides a relevant case in this regard. Over the past several decades, the country has experienced sustained economic growth, industrial transformation, and rising income levels. At the same time, per capita CO_2 emissions have increased markedly, suggesting that economic modernization has not yet been fully decoupled from carbon-intensive development [2], [3]. In other words, the growth process has continued to place increasing pressure on the environment.

Within this broader energy–environment nexus, oil consumption deserves particular attention. Although Vietnam has increasingly emphasized green growth, energy transition, and climate commitments, oil and oil products continue to play an important role in transport, logistics, machinery use, and fuel-based economic activity [4]. This continued dependence matters because oil use is directly associated with combustion-based emissions and may therefore remain an important long-run channel through which economic development translates into environmental pressure.

Despite the policy relevance of this issue, much of the empirical literature has either examined aggregate energy consumption or focused on total emissions rather than per capita environmental pressure [3], [5], [6]. While such approaches are informative, they may obscure the role of specific fossil-energy sources and make interpretation less precise in countries undergoing structural and demographic change. For Vietnam, a more focused analysis of oil consumption and per capita CO_2 emissions is especially useful because it isolates one important fossil-energy channel while also normalizing environmental pressure by population size. In this sense, the use of per capita measures allows a more balanced assessment of emissions intensity over time.

The present study investigates the impact of oil consumption per capita on CO_2 emissions per capita in Vietnam over the period 1990–2024. GDP per capita is included as a control variable to capture the scale effect of economic development on emissions. The paper is grounded in the energy–growth–environment nexus, which suggests that environmental outcomes are jointly shaped by fossil-energy dependence and the scale of economic activity. Within this framework, oil consumption represents a direct fossil-energy channel, while GDP per capita reflects the broader development scale associated with production, mobility, and energy demand. If economic growth remains carbon-intensive, both oil use and income growth are expected to exert positive effects on per capita CO_2 emissions.

Methodologically, the study employs the autoregressive distributed lag (ARDL) approach developed by Pesaran et al. [7]. This framework is appropriate for three reasons. First, it performs well in relatively small samples. Second, it can be applied when variables are integrated of order zero or one, provided that none is integrated of order two. Third, it allows both short-run dynamics and long-run equilibrium relationships to be estimated within a unified specification. These advantages make the ARDL framework particularly suitable for annual time-series data in the Vietnamese context.

The empirical results provide clear support for the study's central argument. The estimated ARDL model confirms the existence of a stable long-run relationship among per capita CO_2 emissions, oil consumption per capita, and GDP per capita. In the long run, oil consumption per capita exerts a positive and statistically significant effect on per capita CO_2 emissions, while GDP per capita also has a positive and significant impact. The error-correction term is negative and significant, indicating relatively rapid adjustment toward long-run equilibrium. Additional checks using an alternative lag-selection criterion and stability tests further support the robustness of the main findings.

This study contributes to literature in three ways. First, it provides updated time-series evidence for Vietnam using annual data covering the period 1990–2024. Second, it focuses specifically on oil consumption rather than aggregate energy use, thereby offering a more targeted perspective on fossil-fuel dependence in Vietnam. Third, by employing per capita measures for CO_2 emissions, oil consumption, and income, the study provides a more population-adjusted assessment of long-run environmental pressure. In this sense, the paper does not attempt to propose an entirely new modeling tradition; rather, it offers focused and policy-relevant empirical evidence on one specific fossil-energy channel in Vietnam's development trajectory.

The remainder of the paper is organized as follows. Section 2 reviews the relevant literature and develops the research hypotheses. Section 3 describes the data, variables, and methodology. Section 4 presents empirical results and discussion. Section 5 concludes the study and offers policy implications.

2. THEORETICAL BACKGROUND, LITERATURE REVIEW, AND HYPOTHESES

2.1. Theoretical background

This study is grounded in the energy–growth–environment nexus, which suggests that environmental outcomes are shaped jointly by fossil-energy dependence and the scale of economic activity. Within this framework, carbon emissions are not determined by energy use alone, but by the interaction between the structure of energy consumption and the broader process of economic development. As economies expand, demand for transport, industrial production, construction, and household energy services tends to increase. When this expansion remains dependent on fossil fuels, environmental pressure is likely to intensify. In this sense, the nexus highlights two interrelated mechanisms: the energy channel, through which fossil-fuel use directly generates emissions, and the scale channel, through which economic growth increases production, mobility, and overall energy demand [1]-[4].

In the context of this nexus, oil consumption represents a direct fossil-energy channel. Unlike broader aggregate measures of energy use, oil consumption is particularly relevant in sectors such as transport, logistics, machinery operation, and other fuel-based activities where combustion-related emissions are immediate and persistent. If an economy remains reliant on oil-intensive systems, higher oil use is expected to increase carbon emissions over time. At the same time, GDP per capita captures the scale effect of development. Rising income generally reflects expanding productive and consumption capacity and, in the absence of cleaner substitution or structural transformation, may also raise environmental pressure. The theoretical expectation is therefore straightforward: if development remains carbon-intensive, both oil consumption per capita and GDP per capita should exert positive effects on CO_2 emissions per capita.

The present study adopts a focused linear framework within the energy–growth–environment nexus. Rather than estimating a nonlinear income turning point, it examines whether oil dependence remains a statistically meaningful long-run driver of per capita CO_2 emissions in Vietnam after controlling for the scale effect of economic development.

2.2. Oil consumption and CO_2 emissions

The relationship between fossil-fuel consumption and carbon emissions is one of the most established themes in environmental and energy economics. From a physical perspective, the connection is direct: the combustion of fossil fuels releases carbon dioxide into the atmosphere. From an economic perspective, sustained dependence on oil, coal, and natural gas tends to raise emissions unless offset by technological upgrading, energy-efficiency gains, or cleaner substitution [1], [2]. Accordingly, a substantial empirical literature has documented a positive association between fossil-energy use and environmental degradation across both developed and developing economies.

Time-series and ARDL-based evidence broadly supports this expectation. Rahman and Kashem [6], for example, show that energy consumption and industrial growth increase carbon emissions in Bangladesh using ARDL cointegration methods. Other studies also find that fossil-fuel dependence remains an important source of emissions pressure, especially in economies where transport, industrial production, and urban expansion continue to rely heavily on oil-based energy systems [3], [5], [8]. These findings are especially relevant when the research objective is not simply to confirm that "energy matters," but to identify the contribution of one specific fossil-energy source.

For this reason, oil consumption per capita is analytically useful. It captures a concrete emissions channel that may otherwise be diluted within broader aggregate energy measures. In economies such as Vietnam, where oil remains central in transport and fuel-based economic activity, focusing on oil consumption allows a more targeted assessment of fossil-fuel dependence than approaches based solely on total energy consumption.

2.3. Economic growth and environmental pressure

A second major strand of the literature concerns the role of economic growth in shaping environmental outcomes. In developing economies, rising income is often associated with expanding industrial output, greater transport demand, larger infrastructure investment, and higher household energy consumption. Under such conditions, GDP per capita is expected to increase environmental pressure, particularly when production and mobility systems remain carbon-intensive [5]-[11].

Empirical literature generally finds a positive relationship between income growth and emissions, although the magnitude differs across countries and model specifications. Rahman and Kashem [6] report that economic and industrial expansion is associated with higher carbon emissions in Bangladesh. Broader cross-country evidence similarly suggests that economic growth and industrialization continue to raise emissions in many developing and middle-income economies [5]-[10]. For Vietnam, Nguyen et al. [3] find that economic growth and fossil fuel use are positively associated with greenhouse gas emissions, while Raihan [9] shows that economic expansion remains an important driver of CO_2 emissions, even though some structural factors may moderate this effect over time.

Taken together, this literature implies that GDP per capita should not be treated as merely background control. Rather, it reflects the broader development scale within which fossil-energy use takes place. If growth remains energy-intensive and carbon-intensive, the scale effect of income is expected to increase CO_2 emissions per capita.

2.4. Evidence from Vietnam and the research gap

For Vietnam, the energy–environment nexus has received growing scholarly attention, but much of the existing evidence focuses on broad energy aggregates, total greenhouse gas emissions, or multi-variable systems that do not isolate the specific role of oil consumption. Nguyen et al. [3] examine the nexus among greenhouse gases, economic growth, energy, and trade openness in Vietnam and find that GDP and fossil-fuel use increase emissions. Raihan [9] likewise reports that economic growth and energy-related factors continue to exert upward pressure on CO_2 emissions in Vietnam. These studies provide useful evidence, but they mainly emphasize general energy use or broader emissions indicators rather than the specific linkage between oil consumption per capita and CO_2 emissions per capita.

This leaves two gaps. First, relatively less attention has been paid to oil consumption per capita as a distinct explanatory variable, despite the fact that oil remains central in transport and fuel-based economic activity. Second, fewer studies focus explicitly on CO_2 emissions per capita, which is a useful outcome measure when the objective is to assess environmental pressure relative to population size rather than in aggregate national totals. By concentrating on the relationship between oil consumption per capita and CO_2 emissions per capita, while controlling for GDP per capita, the present study offers a more focused test of one important fossil-energy mechanism in Vietnam's development trajectory.

In this respect, the contribution of the present study does not lie in proposing a new theoretical paradigm, but in providing focused, updated, and policy-relevant evidence on one specific fossil-energy channel in Vietnam. By isolating oil consumption per capita and linking it to CO_2 emissions per capita within the energy–growth–environment nexus, the study offers a more targeted assessment of fossil-fuel dependence than approaches based on broad aggregate energy measures.

2.5. Research hypotheses

Based on the theoretical framework and prior empirical evidence, the study expects both oil dependence and the scale effect of economic growth to exert positive pressure on per capita CO_2 emissions in Vietnam. Accordingly, two hypotheses are proposed.

H1. Oil consumption per capita has a positive effect on CO_2 emissions per capita in Vietnam.

This hypothesis follows directly from the fossil-fuel emissions mechanism and is consistent with prior evidence showing that oil and fossil-energy use tend to increase carbon emissions over both the short and long [5], [3], [6], [8].

H2. GDP per capita has a positive effect on CO_2 emissions per capita in Vietnam.

This hypothesis is grounded in the literature showing that, in economies where development remains energy-intensive, rising income is associated with increasing environmental pressure [3], [5], [9].

Accordingly, the empirical model is designed to test whether per capita CO_2 emissions in Vietnam are systematically associated with per capita oil consumption after controlling for the level of economic development.

3. DATA, VARIABLES, AND METHODOLOGY

3.1. Data sources and study period

This study uses annual time-series data for Vietnam covering the period 1990–2024. The dataset is constructed from two widely used international sources. Data on CO_2 emissions per capita and oil consumption per capita are obtained from Our World in Data, while GDP per capita is collected from the World Bank's World Development Indicators database. CO_2 emissions per capita are measured in tonnes per person, oil consumption per capita is measured in kilowatt-hours per person, and GDP per capita is measured in constant 2015 U.S. dollars.

The use of annual data is motivated by both data availability and methodological consistency. For Vietnam, long and comparable annual series are more reliable than higher-frequency series for the variables considered here. The sample begins in 1990 to capture the country's post-reform development trajectory and extends to 2024 to incorporate the most recent observations available in the dataset. After the inclusion of lags in the ARDL framework, the effective estimation sample is reduced to 1992–2024.

3.2. Variable definition and measurement

The study focuses on three variables. The dependent variable is CO_2 emissions per capita (co2), which captures environmental pressure at the individual level rather than in aggregate national totals. This variable is transformed into its natural logarithm, denoted as ln_co2pc. Using the per capita form is appropriate because it normalizes national emissions by population size and provides a more balanced measure of environmental intensity over time.

The main explanatory variable is oil consumption per capita (oil_pc), transformed into logarithmic form as ln_oilpc. This variable is used to isolate the role of oil-based energy use in Vietnam's emissions trajectory. It is particularly relevant because oil remains central in transport, logistics, machinery use, and other fuel-based economic activities.

The control variable is GDP per capita (gdp_pc), transformed into logarithmic form as ln_gdppc. GDP per capita is included to capture the scale effect of economic development on environmental outcomes. In developing economies, rising income often increases demand for energy, mobility, and production, all of which can intensify emissions when growth remains carbon-intensive.

All three variables are expressed in natural logarithms. This transformation serves two purposes. First, it helps stabilize the variance of macro time-series data. Second, it allows the estimated coefficients to be interpreted as elasticities, which is particularly useful for policy-oriented analysis.

3.3. Model specification

To examine the long-run effect of oil consumption on CO_2 emissions, the study specifies the following baseline relationship:

$$ln\ ln\ CO2PC_t = \beta_0 + \beta_1\ ln\ ln\ OILPC_t + \beta_2\ ln\ ln\ GDPPC_t + u_t$$

where $lnCO2PC_t$ denotes the logarithm of CO_2 emissions per capita, $lnOILPC_t$ is the logarithm of oil consumption per capita, and $lnGDPPC_t$ is the logarithm of GDP per capita.

The expected signs of the coefficients are positive. A higher level of oil consumption per capita is expected to increase per capita CO_2 emissions because oil combustion directly releases carbon dioxide. Likewise, higher GDP per capita is expected to raise emissions if economic growth remains associated with fossil-fuel-based production and consumption patterns.

The empirical specification is intentionally parsimonious. Given the relatively small annual sample, the model is designed to isolate the long-run effect of oil consumption per capita while controlling economic development through GDP per capita. Other structural determinants, such as renewable energy use, trade openness, urbanization, and industrial restructuring, are acknowledged as potentially relevant but are treated as issues for robustness checks and future research rather than as part of the core baseline specification.

3.4. Econometric approach

This study employs the autoregressive distributed lag (ARDL) approach developed by Pesaran et al. [7]. The ARDL framework is suitable for three main reasons. First, it performs well in relatively small samples. Second, it can be applied when variables are integrated of order zero or one, provided that none is integrated of order two. Third, it allows both short-run dynamics and long-run equilibrium relationships to be estimated within a unified framework.

Before estimating the ARDL model, the stationarity properties of the variables are examined using the Augmented Dickey–Fuller (ADF) test. The results indicate that ln_co2pc, ln_oilpc, and ln_gdppc are non-stationary in levels but become stationary after first differencing. This means that all three variables are integrated of order one, I(1), which is consistent with the use of the ARDL approach.

The general ARDL model can be written as:

$$\Delta \ ln \ ln \ CO2PC_t = \alpha_0 + \sum_{i=1}^{p} \alpha_i \Delta \ ln \ ln \ CO2PC_{t-i} + \sum_{j=0}^{q} \gamma_j \Delta \ ln \ ln \ OILPC_{t-j} + \sum_{k=0}^{m} \delta_k \Delta \ ln \ ln \ GDPPC_{t-k} + \phi_1 \ ln \ ln \ CO2PC_{t-1} + \phi_2 \ ln \ ln \ OILPC_{t-1} + \phi_3 \ ln \ ln \ GDPPC_{t-1} + \epsilon_t$$

where Δ denotes the first-difference operator and the lagged level terms capture the long-run relationship among the variables.

After evaluating alternative lag structures, the preferred specification for the baseline model, selected by the Akaike Information Criterion, is ARDL (2,0,0). The same lag structure is also obtained under the Bayesian Information Criterion, which provides additional support for the stability of the selected model.

3.5. Estimation procedure

The empirical analysis proceeds in several steps. First, descriptive statistics are reported to summarize the distributional characteristics of the variables. Second, a correlation matrix is examined to assess the strength and direction of pairwise associations among the logged variables. Third, ADF unit root tests are applied to determine the order of integration. Fourth, the ARDL bounds testing procedure is employed to examine whether a long-run relationship exists among the variables. Fifth, conditional on the existence of cointegration, the ARDL model is estimated and decomposed into long-run and short-run components.

After estimating the baseline model, a set of post-estimation diagnostic tests is conducted to evaluate model adequacy, including tests for serial correlation, heteroskedasticity, and functional form. To strengthen confidence in the results, the study also performs robustness and stability checks. Specifically, the main findings are re-examined using an alternative lag-selection criterion (BIC), and parameter stability is assessed using cumulative sum (CUSUM) tests. These additional checks help address concerns regarding model sensitivity and structural instability.

4. EMPIRICAL RESULTS AND DISCUSSION

4.1. Descriptive statistics and time-series patterns

Table 1. Descriptive Statistics of the Variables

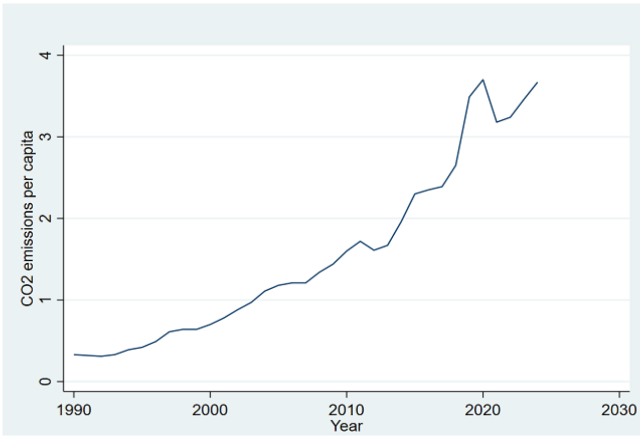
Variable	N	Mean	SD	Min	P25	P50	P75	Max
co2	35	1.5511	1.0902	0.3100	0.6400	1.2100	2.3500	3.7000
oil_pc	35	1981.9920	982.2495	510.8322	1124.6550	1976.9140	2893.5440	3851.6280
gdp_pc	35	1953.7870	978.6871	687.8603	1110.1130	1788.9490	2715.5790	4017.7460
ln_co2pc	35	0.1642	0.7920	-1.1712	-0.4463	0.1906	0.8544	1.3083
ln_oilpc	35	7.4439	0.5908	6.2360	7.0252	7.5893	7.9702	8.2563
ln_gdppc	35	7.4486	0.5266	6.5336	7.0122	7.4894	7.9068	8.2985

Note: co2 denotes CO_2 emissions per capita, oil_pc denotes oil consumption per capita, and gdp_pc denotes GDP per capita (constant 2015 U.S. dollars). Logarithmic variables are constructed by the author for econometric estimation.

Source: Author's calculations based on data from Our World in Data and World Development Indicators (World Bank).

Table 1 reports the descriptive statistics of the variables used in the analysis. The dataset consists of 35 annual observations covering the period 1990–2024. As shown in Table 1, per capita CO_2 emissions (co2) have a mean value of 1.551, with values ranging from 0.310 to 3.700. Oil consumption per capita (oil_pc) averages 1,981.992 kWh per person and varies from 510.832 to 3,851.628. GDP per capita (gdp_pc) has a mean of 1,953.787 constant 2015 U.S. dollars, with a minimum of 687.860 and a maximum of 4,017.746. The logged variables also exhibit sufficient variation for time-series estimation, with standard deviations of 0.792 for ln_co2pc, 0.591 for ln_oilpc, and 0.527 for ln_gdppc. These results indicate that the series contain meaningful dispersion and are suitable for further econometric analysis.

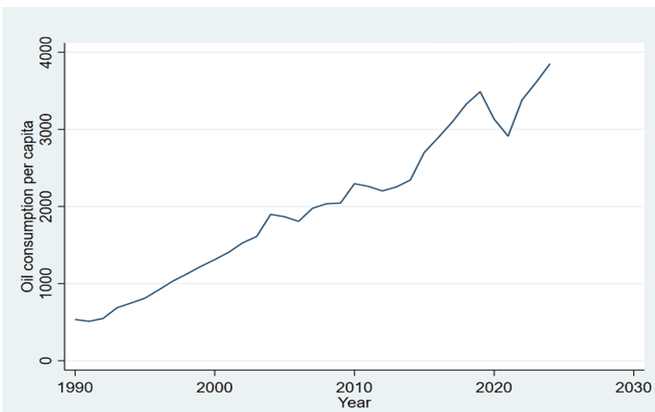
Figure 1. CO_2 Emissions per Capita in Vietnam



Source: Author's illustration based on data from Our World in Data.

Figure 1 shows the evolution of per capita CO_2 emissions in Vietnam. The series follows a clear upward trend over the sample period, indicating that environmental pressure has increased substantially over time. This pattern is consistent with the descriptive evidence in Table 1 and suggests that Vietnam's development process has been accompanied by rising per capita emissions.

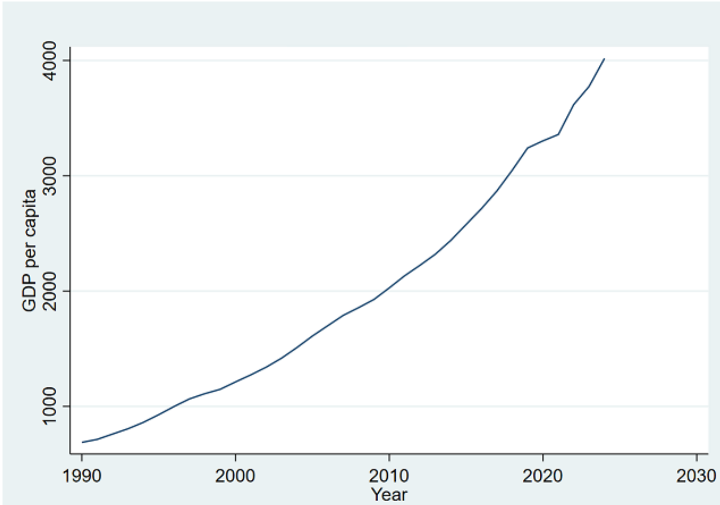
Figure 2. Oil Consumption per Capita in Vietnam



Source: Author's illustration based on data from Our World in Data.

Figure 2 presents the trend in oil consumption per capita. Similar to CO_2 emissions, oil use per capita rises markedly over time, although some fluctuations are visible. The overall upward movement suggests that oil remains an important component of Vietnam's energy use and may be closely linked to the country's emissions trajectory.

Figure 3. GDP per Capita in Vietnam



Source: Author's illustration based on data from World Development Indicators (World Bank).

Figure 3 displays the movement of GDP per capita. The figure reveals a strong and persistent upward trend, reflecting Vietnam's sustained economic growth during the study period. Taken together, Figures 1–3 suggest that rising income, increasing oil consumption, and expanding CO_2 emissions have moved broadly in the same direction, thereby providing initial support for the existence of a long-run relationship among the variables.

4.2. Correlation analysis

Table 2. Pairwise Correlation Matrix

Variable	ln_co2pc	ln_oilpc	ln_gdppc
ln_co2pc	1.0000	0.9838	0.9945
ln_oilpc	0.9838	1.0000	0.9790
ln_gdppc	0.9945	0.9790	1.0000

Note: All pairwise correlations are positive and statistically significant at the 1% level.

Source: Author's calculations based on Stata output.

Table 2 reports the pairwise correlations among the logged variables. The correlation coefficient between ln_co2pc and ln_oilpc is 0.9838, while the correlation between ln_co2pc and ln_gdppc is 0.9945. In addition, the correlation between ln_oilpc and ln_gdppc is 0.9790. All coefficients are positive and statistically significant at the 1% level. These results indicate a very strong positive association among per capita CO_2 emissions, oil consumption per capita, and GDP per capita in Vietnam.

At the same time, the very high pairwise correlations suggest that the variables share strong common upward trends over time. This result reinforces the importance of formal unit root and cointegration testing, since correlation alone is insufficient for establishing a meaningful long-run relationship in macro time-series data.

The very high pairwise correlations may raise concerns regarding multicollinearity and common trending behavior. However, such patterns are not unusual in macroeconomic time-series characterized by strong long-run upward trends. For this reason, the present study does not interpret correlation coefficients as evidence of a meaningful long-run relationship by themselves. Instead, the issue is addressed through formal unit root testing, the ARDL bounds testing procedure, and the error-correction specification. The results confirm that the variables are integrated of order one, cointegrated, and dynamically stable, which reduces the risk that the main findings are driven merely by common trends.

4.3. Unit root tests

Table 3. Augmented Dickey–Fuller Unit Root Test Results

Variable	Level: ADF statistic	p-value	First difference: ADF statistic	p-value	Order of integration
ln_co2pc	-1.172	0.6854	-6.508	0.0000	I(1)
ln_oilpc	-2.704	0.0734	-4.435	0.0003	I(1)
ln_gdppc	-1.693	0.4348	-3.722	0.0038	I(1)

Note: All variables are non-stationary in levels but become stationary after first differencing, supporting the use of the ARDL approach.

Source: Author's calculations based on Stata output.

Table 3 presents the results of the Augmented Dickey–Fuller unit root tests. At levels, none of the three variables is stationary at the 5% significance level. Specifically, the ADF statistic for ln_co2pc is -1.172 with a p-value of 0.6854, the statistic for ln_oilpc is -2.704 with a p-value of 0.0734, and the statistic for ln_gdppc is -1.693 with a p-value of 0.4348. These results imply that the null hypothesis of a unit root cannot be rejected in levels.

However, all three variables become stationary after first differencing. The ADF statistics for d_ln_co2pc, d_ln_oilpc, and d_ln_gdppc are -6.508, -4.435, and -3.722, respectively, with corresponding p-values of 0.0000, 0.0003, and 0.0038. Therefore, all variables are integrated of order one, I(1), and none is integrated of order two. This result supports the use of the ARDL framework in the next stage of the analysis.

4.4. ARDL bounds test

Table 4. ARDL Bounds Test for the Existence of a Long-Run Relationship

Test statistic	Value	10% critical bounds	5% critical bounds	1% critical bounds	Decision
F-statistic	19.909	I(0) = 3.390; I(1) = 4.457	I(0) = 4.193; I(1) = 5.407	I(0) = 6.118; I(1) = 7.661	Reject H_0
t-statistic	-7.191	I(0) = -2.583; I(1) = -3.240	I(0) = -2.932; I(1) = -3.627	I(0) = -3.647; I(1) = -4.410	Reject H_0

Note: H_0: no level relationship exists among the variables. Both statistics are more extreme than the upper critical bounds at the 10%, 5%, and 1% levels, confirming the existence of a long-run relationship.

Source: Author's calculations based on Stata estimation results.

Before interpreting the long-run and short-run coefficients, it is necessary to verify whether a stable levels relationship exists among the variables. For this purpose, the study applies the Pesaran–Shin–Smith bounds testing procedure within the ARDL framework. As reported in Table 4, the computed F-statistic is 19.909 and the associated t-statistic is -7.191. Both statistics are more extreme than the upper critical values at the 10%, 5%, and 1% significance levels. The null hypothesis of no level relationship is therefore rejected at all conventional significance levels.

The bounds test result provides strong evidence of cointegration among ln_co2pc, ln_oilpc, and ln_gdppc. In substantive terms, this means that per capita CO_2 emissions, oil consumption per capita, and GDP per capita move together over time in a stable long-run equilibrium relationship. This finding justifies the use of the ARDL error-correction specification and provides a formal basis for interpreting the long-run coefficients reported in the next subsection.

4.5. ARDL estimation results

Table 5. ARDL Estimation Results

Dependent variable: ΔlnCO2PCt
Selected model: ARDL (2,0,0)
Sample: 1992–2024
Number of observations: 33
R-squared = 0.6993; Adjusted R-squared = 0.6564; Root MSE = 0.0474

Panel A. Error-correction term

Variable	Coefficient	Std. Error	t-statistic	p-value	95% CI
L1.ln_co2pc	-0.7484	0.1041	-7.19	0.000	[-0.9615, -0.5352]

Panel B. Long-run coefficients

Variable	Coefficient	Std. Error	t-statistic	p-value	95% CI
ln_oilpc	0.4513	0.1116	4.05	0.000	[0.2228, 0.6799]
ln_gdppc	1.0341	0.1211	8.54	0.000	[0.7861, 1.2820]

Panel C. Short-run coefficients

Variable	Coefficient	Std. Error	t-statistic	p-value	95% CI
LD.ln_co2pc	0.4319	0.1114	3.88	0.001	[0.2038, 0.6601]
Constant	-8.1754	1.1865	-6.89	0.000	[-10.6058, -5.7451]

Note: The preferred specification selected by the Akaike Information Criterion is ARDL (2,0,0). The negative and significant error-correction coefficient indicates convergence toward long-run equilibrium.

Source: Author's calculations based on Stata estimation results.

Table 5 reports the results of the preferred ARDL specification. Based on the Akaike Information Criterion, the selected model is ARDL (2,0,0), estimated over the period 1992–2024 with 33 observations. The model produces an R-squared of 0.6993 and an adjusted R-squared of 0.6564, which are acceptable for a parsimonious annual time-series specification.

The long-run coefficient on ln_oilpc is 0.4513 and is statistically significant at the 1% level. This indicates that, holding GDP per capita constant, a 1% increase in oil consumption per capita is associated with an approximately 0.451% increase in CO_2 emissions per capita in the long run. This finding provides strong support for the first hypothesis and confirms that oil consumption remains an important driver of emissions in Vietnam.

Table 5 also shows that GDP per capita has a positive and highly significant long-run effect on emissions. The coefficient on ln_gdppc is 1.0341, indicating that a 1% increase in GDP per capita is associated with a 1.034% increase in CO_2 emissions per capita in the long run. The magnitude of this elasticity suggests that Vietnam's development path has remained closely linked to rising carbon emissions and that economic growth has not yet been meaningfully decoupled from environmental pressure.

The adjustment dynamics are also economically meaningful. As reported in Table 5, the coefficient on the lagged error-correction term is -0.7484 and highly significant. The negative sign confirms convergence toward long-run equilibrium, while the magnitude implies that approximately 74.8% of short-run disequilibrium is corrected within one year. In addition, the lagged first difference of ln_co2pc is positive and significant, with a coefficient of 0.4319, indicating short-run persistence in the emissions process. Taken together, these results suggest that Vietnam's emissions trajectory is influenced by both persistent long-run forces and short-run dynamic adjustment.

4.6. Diagnostic tests and model adequacy

Table 6. Diagnostic Test Results

Test	Statistic	p-value	Conclusion
Breusch–Godfrey LM test for serial correlation	$\chi^2 = 0.409$	0.5224	No evidence of serial correlation
Breusch–Pagan / Cook–Weisberg test for heteroskedasticity	$\chi^2 = 1.76$	0.1851	No evidence of heteroskedasticity
Ramsey RESET test	$F(3, 25) = 2.45$	0.0866	Model specification acceptable at the 5% level

Note: The diagnostic results indicate that the estimated ARDL model does not suffer from serious autocorrelation or heteroskedasticity problems. Although the RESET test is relatively close to conventional significance thresholds, the null hypothesis of correct functional form is not rejected at the 5% level.

Source: Author's calculations based on Stata estimation results.

Table 6 reports the post-estimation diagnostic tests for the baseline model. The Breusch–Godfrey LM test yields a p-value of 0.5224, indicating no evidence of serial correlation. The Breusch–Pagan/Cook–Weisberg test produces a p-value of 0.1851, suggesting that heteroskedasticity is not a serious concern. The Ramsey RESET test reports a p-value of 0.0866. Although this value is relatively close to conventional thresholds, the null hypothesis of correct specification is not rejected at the 5% level. Taken together, these results indicate that the model is broadly acceptable and does not suffer from severe misspecification problems.

Diagnostic evidence strengthens the credibility of the main estimates. The absence of serious autocorrelation and heteroskedasticity implies that the coefficient estimates and standard errors reported in Table 5 are reasonably reliable. While the RESET result suggests some caution at more lenient significance thresholds, it does not invalidate the model at the conventional 5% level.

4.7. Stability and robustness checks

Table 7. Robustness Check Using the BIC Criterion

Criterion	Selected ARDL model	Long-run oil effect	Long-run GDP effect	ECM	Conclusion
AIC	ARDL (2,0,0)	0.4513***	1.0341***	-0.7484***	Baseline model
BIC	ARDL (2,0,0)	0.4513***	1.0341***	-0.7484***	Robust

Note: Using the Bayesian Information Criterion (BIC) yields the same preferred specification, ARDL (2,0,0), and identical key coefficient estimates as the baseline model selected by the Akaike Information Criterion (AIC). This supports the robustness of the main results to alternative lag-selection criteria.

Source: Author's calculations based on Stata estimation results.

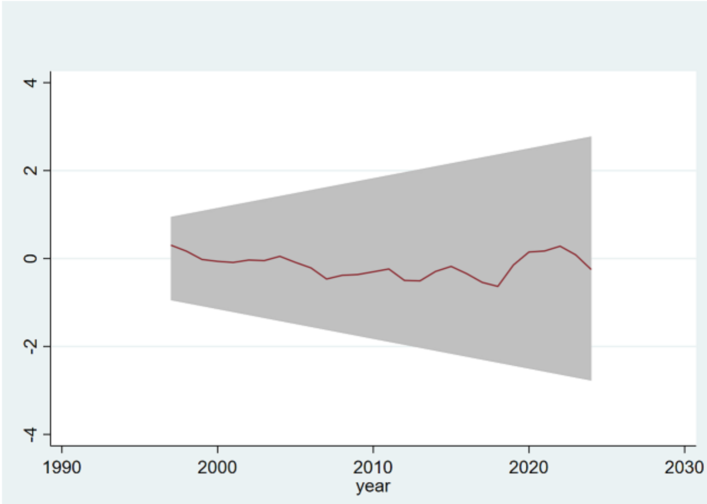


Figure 4. CUSUM Test

Source: Author's illustration based on Stata estimation results.

To strengthen confidence in the baseline results, the study performs both robustness and stability checks. First, the ARDL model is re-estimated using the Bayesian Information Criterion instead of the Akaike Information Criterion for lag selection. The alternative lag-selection procedure produces the same preferred specification, ARDL (2,0,0), and yields identical coefficient estimates, bounds test results, and diagnostic statistics. This indicates that the main findings are not sensitive to the choice between AIC and BIC. In particular, the positive long-run effects of oil consumption per capita and GDP per capita on CO_2 emissions per capita remain unchanged.

Second, parameter stability is examined using cumulative sum tests. The recursive CUSUM statistic is 0.2843, while the OLS-based CUSUM statistic is 0.4546. Both values are well below the corresponding 10%, 5%, and 1% critical values, indicating no evidence of structural instability over the sample period. These results suggest that the estimated coefficients are stable and that the baseline relationship is not driven by structural breaks. Additional CUSUMSQ series were also generated as supplementary evidence, further supporting the stability of the estimated model.

Taken together, the robustness and stability checks strengthen confidence in the baseline ARDL results. They suggest that the positive long-run relationship among oil consumption, income, and CO_2 emissions in Vietnam is not merely an artifact of a particular lag-selection criterion or of parameter instability.

The fact that the same ARDL specification is selected under both AIC and BIC, together with the absence of structural instability in the CUSUM tests, suggests that the baseline findings are not simply artifacts of common trending behavior or unstable parameter estimates.

4.8. Discussion

The empirical results reveal a consistent and theoretically coherent pattern. The descriptive statistics and graphical evidence show that per capita CO_2 emissions, oil consumption per capita, and GDP per capita all follow a marked upward trend over the sample period, suggesting that Vietnam's economic transformation has been accompanied by rising fossil-energy use and increasing environmental pressure. The correlation matrix further indicates strong positive associations among the three variables, while the unit root tests confirm that the series are integrated of order one. Most importantly, the bounds test provides clear evidence of a long-run relationship, and the estimated ARDL model shows that both oil consumption per capita and GDP per capita exert positive and statistically significant long-run effects on CO_2 emissions per capita in Vietnam.

The positive long-run elasticity of oil consumption per capita is particularly important. It suggests that oil use is not merely correlated with emissions because of common upward trends but constitutes a substantive driver of Vietnam's per capita CO_2 emissions. This finding is fully consistent with the theoretical expectation that continued dependence on fossil-fuel-based energy use intensifies carbon emissions over time. In the Vietnamese context, where oil remains heavily used in transport, logistics, machinery, and fuel-based economic activities, the result indicates that oil consumption continues to be a structurally relevant channel through which development translates into environmental pressure.

The estimated coefficient on GDP per capita is also positive, statistically significant, and larger in magnitude than that of oil consumption. This implies that the rise in emissions is not attributable to energy use alone but is embedded in a broader pattern of growth in which economic expansion remains carbon intensive. In other words, the results suggest that Vietnam has not yet achieved a meaningful decoupling of income growth from per capita CO_2 emissions during the period under study. This interpretation is consistent with earlier studies for Vietnam and other developing economies that report a positive relationship between growth and environmental pressure, while the present study sharpens that perspective by isolating oil consumption as a specific fossil-energy channel rather than relying on aggregate energy measures.

The dynamic adjustment mechanism also adds to the interpretation of the findings. The negative and highly significant error-correction coefficient indicates that deviations from the long-run equilibrium are corrected relatively quickly, implying that the relationship among emissions, oil consumption, and income is not only statistically detectable but also dynamically stable. The positive short-run coefficient on the lagged first difference of emissions further suggests that the emissions process exhibits inertia, meaning that recent changes in emissions continue to influence current movements. Together, these results indicate that Vietnam's carbon-emissions trajectory is shaped by both persistent long-run forces and short-run dynamic adjustment.

Finally, the additional robustness and stability checks reinforce the reliability of the baseline findings. The fact that the same ARDL specification is selected under both AIC and BIC, together with the absence of evidence of structural instability in the CUSUM tests, suggests that the main conclusions are not driven by arbitrary lag selection or by major parameter instability. Therefore, the empirical evidence supports a clear conclusion at the discussion stage: Vietnam's per capita CO_2 emissions remain systematically linked to oil dependence and income expansion, and this relationship is statistically robust within the selected ARDL framework.

5. CONCLUSION AND POLICY IMPLICATIONS

This study investigates the impact of oil consumption on per capita CO_2 emissions in Vietnam over the period 1990–2024 using an ARDL framework. The empirical results lead to three main conclusions. First, the bounds test confirms the existence of a stable long-run relationship among per capita CO_2 emissions, oil consumption per capita, and GDP per capita. Second, oil consumption per capita exerts a positive and statistically significant long-run effect on per capita CO_2 emissions. Third, GDP per capita also has a positive and highly significant effect, indicating that Vietnam's growth trajectory has remained closely associated with rising environmental pressure. In addition, the negative and significant error-correction term confirms relatively rapid adjustment toward long-run equilibrium after short-run deviations.

These findings together suggest that Vietnam's emissions path continues to be shaped by both fossil-fuel dependence and carbon-intensive economic growth.

From a substantive perspective, the study shows that oil consumption is not a peripheral factor in Vietnam's environmental performance. Rather, it remains a meaningful long-run driver of per capita CO_2 emissions. At the same time, the positive income elasticity indicates that economic expansion has not yet been decoupled from carbon emissions. This implies that growth alone cannot be assumed to generate environmental improvement unless accompanied by structural change in energy use and production patterns.

The policy implications are clear. First, reducing dependence on oil-intensive transport and logistics systems should be a priority. This includes improving fuel efficiency, promoting cleaner public transport, supporting electric mobility where feasible, and upgrading freight systems that still rely heavily on fossil fuels. Second, climate policy should be integrated more closely with development strategy. Since GDP growth continues to exert upward pressure on emissions, industrial modernization, low-carbon urban development, and energy-efficient production should be treated as core components of economic policy rather than as secondary environmental measures. Third, Vietnam's long-run transition toward sustainability will require stronger substitution away from oil-based energy use through cleaner technologies, more diversified energy sources, and incentives that gradually reduce the carbon intensity of growth.

This study is subject to some limitations. The empirical model is intentionally parsimonious and focuses on oil consumption and income as the two core determinants of per capita CO_2 emissions. While this improves interpretability, it does not explicitly incorporate other potentially relevant factors, such as renewable energy expansion, technological progress, trade openness, industrial restructuring, or environmental regulation. In addition, the use of annual aggregate data does not allow sector-specific transmission channels to be examined in detail.

Future research may extend the analysis by incorporating broader energy-structure variables, testing the robustness of the results with alternative long-run estimators, or examining sector-level emissions dynamics. Nevertheless, the central conclusion of this study remains clear: if Vietnam seeks to sustain economic growth while meeting environmental commitments, reducing dependence on oil-based energy use will be essential for a more sustainable long-run development path.

Acknowledgement: This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors. The authors would also like to thank colleagues and reviewers for their helpful comments on earlier versions of the paper.

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