



ECONOMIC DEVELOPMENT AND ENVIRONMENTAL POLLUTION: EVIDENCE FROM CO₂ EMISSIONS EFFICIENCY IN VIETNAM

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Abstract. This study examines the drivers of carbon dioxide (CO₂) emissions efficiency in Vietnam, focusing on the relationship between economic growth (GDP–gross domestic product), industrial output (IND), access to electricity (ELC–proportion of population with reliable and affordable electricity), and urbanization (URB– share of population living in urban areas). We employ time-series econometric methods on annual data for Vietnam (1990–2020). The method of Autoregressive Integrated Moving Average (ARIMA) and an Autoregressive Distributed Lag (ARDL) model are employed for estimating. The ARDL framework is used to capture both short-run dynamics and long-run equilibrium relationships. Key findings show that long-run electricity access is significantly associated with lower CO₂ emissions intensity, while long-run urbanization significantly raises emissions intensity. Historical persistence of emissions is also evident. These results suggest that policies promoting clean electricity expansion and sustainable urban planning can reduce CO₂ emissions per unit of GDP while supporting development.

Keywords: CO₂ emissions, economic growth, middle-income countries, pollution, JEL: G33, N74

1 Introduction

Vietnam has been one of the fastest-growing economies in Southeast Asia, recording average GDP growth of 6–7% annually since the 1990s [1]. This growth, however, has been accompanied by rising CO₂ emissions, raising pressing concerns about environmental sustainability [2, 3]. As Vietnam transitions from an agricultural economy toward an industrial and service-oriented structure, the challenge of balancing growth with environmental protection has become more urgent [2].

Measuring CO₂ emissions efficiency—defined as CO₂ emissions per unit of GDP (PPP \$)—provides a relative indicator of how effectively economic output is generated with minimal environmental cost. By examining efficiency rather than absolute emissions, this study highlights how resource use translates into carbon intensity of growth. The analysis is particularly relevant for Vietnam, where emissions efficiency lags behind countries of similar income levels [3].

Vietnam has undertaken major investments in renewable energy and environmental regulations, including expansion of solar and wind power [4, 5]. Yet, fossil fuels still dominate the energy mix, and rapid industrialization and urbanization continue to put upward pressure on emissions [6, 7]. International and domestic debates increasingly stress that improved electricity access can only reduce emissions if coupled with clean generation, while unchecked urban expansion risks locking in carbon-intensive development [8].

This study therefore contributes by empirically assessing the roles of GDP growth, industrialization, electricity access, and urbanization in shaping Vietnam's CO₂ emissions efficiency. Unlike much of the existing research that emphasizes either growth or renewable adoption, we focus on the joint dynamics of these drivers. Our results are compared directly with earlier studies on Vietnam and the wider Environmental Kuznets Curve (EKC) debate in emerging economies, offering new evidence to guide policy interventions toward low-carbon development.

2 Literature review

The relationship between development and CO₂ emissions in Vietnam has been explored through multiple lenses. Studies on foreign direct investment (FDI) and urbanization emphasize their dual role: while FDI boosts industrial output and growth, it often increases energy consumption and emissions. Urbanization amplifies this effect by raising demand for housing, transport, and energy infrastructure. Ngoc, Tuan, and Duy [8] demonstrate that FDI and urban development significantly increase emissions, while Minh et al. [6] show that urban population growth intensifies energy use and CO₂ output. These findings highlight the tension between growth and

sustainability, reinforcing the need for carefully managed urban expansion with environmental safeguards.

Research on renewable energy and green finance provides a contrasting perspective. Hoffmann [4] and Tran [5] show that renewable energy investment and green financing mechanisms can lower CO₂ intensity and help Vietnam meet its emission-reduction targets. These results support the Environmental Kuznets Curve (EKC) hypothesis [7], which suggests that emissions first rise with growth but later decline as income levels and environmental investments increase. For Vietnam, the evidence remains mixed: while renewable expansion offers promise, its benefits depend critically on displacing fossil-based generation.

Sector-specific analyses further reveal that industrialization, export-led manufacturing, and energy-intensive industries remain primary contributors to emissions. Structural decomposition studies by Nguyen [2] and Raihan [3] identify industrial output as a key driver of Vietnam's carbon intensity, while Nguyen [9] highlights the role of renewable energy—particularly wind power—in reducing fossil dependence. Together, the literature underscores two countervailing forces: (i) rapid industrialization and urban growth that raise emissions, and (ii) electrification and clean-energy investments that can reduce emissions intensity.

Despite these contributions, significant gaps remain. Few studies explicitly analyze emissions efficiency (CO₂ per GDP) as opposed to absolute emissions. Moreover, the extent to which electricity access, urbanization, and industrial output interact in shaping efficiency has not been systematically examined in Vietnam. This study addresses this gap by applying time-series econometric methods to capture both short-run and long-run effects, thereby contributing new evidence to policy debates in Vietnam and other emerging economies facing similar trade-offs between growth and environmental sustainability.

3 Data and methodological overview

This section integrates both data resources and methods. Annual data for Vietnam from 1990 to 2020 were collected from the World Bank's World Development Indicators (WDI). The dependent variable is CO₂ emissions efficiency, measured as CO₂ emissions per unit of GDP (PPP \$). Independent variables include GDP growth, industrial output (IND), access to electricity (ELC), and urbanization (URB). Institutional quality data are drawn from the World Bank's Worldwide Governance Indicators (WGI), while energy structure indicators (renewables and fossil fuels) come from the International Energy Agency (IEA).

The methodology proceeds in several steps. Correlation and descriptive statistics establish preliminary relationships and detect multicollinearity. Unit root and stationarity tests (ADF, Levin-Lin-Chu, Im-Pesaran-Shin) ensure the validity of time-series modelling.

Autoregressive (AR) and ARIMA models capture dynamic patterns, while the ARDL model assesses both short- and long-run relationships. The ARDL framework is particularly suitable, as it accommodates mixed integration orders (I (0) and I (1)) and small-sample data, making it the most policy-relevant model for this study.

4 Methodology, result and discussion

The correlation matrix shows a moderate positive relationship between CO₂ emissions efficiency and both access to electricity (ELC = 0.587) and urbanization (URB = 0.558). This indicates that increases in electricity access and urbanization are associated with higher CO₂ emissions per unit of GDP. However, the very high correlation between ELC and URB (0.898) signals potential multicollinearity, which could distort regression estimates. To address this issue, Variance Inflation Factor (VIF) tests were performed in the regression stage, and the results confirmed acceptable levels of multicollinearity (VIF values < 10). Additionally, robustness checks were run by alternately including and excluding ELC and URB to ensure that the final ARDL estimates remained stable.

Table 1. Correlation Matrix

	CO2	ELC	GDP	IND	URB
CO2	1.000000	0.587490	-0.086840	0.156366	0.557710
ELC	0.587490	1.000000	-0.165028	0.070982	0.898465
GDP	-0.086840	-0.165028	1.000000	0.084286	-0.170177
IND	0.156366	0.070982	0.084286	1.000000	-0.081251
URB	0.557710	0.898465	-0.170177	-0.081251	1.000000

The descriptive statistics reveal important insights into the dataset. CO₂ emissions efficiency (CO₂/GDP) averages 0.27, with relatively low variability (Std. Dev. = 0.028), indicating a stable but persistently high emissions intensity. Access to electricity (ELC) is very high, averaging 94% of the population, though the minimum value of 78.4% reflects earlier stages of electrification. GDP growth is volatile (Std. Dev. = 1.40), reflecting Vietnam’s rapid transition from an agricultural to an industrial economy. Industrial output (IND) averages 34% of GDP, highlighting the importance of manufacturing in driving both growth and emissions. Urbanization (URB) averages 27.8%, but the steady rise toward 37% illustrates the structural demographic shift.

Table 2. Descriptive statistics

	CO2	ELC	GDP	IND	URB
Mean	0.269872	94.32793	6.750477	34.19244	27.81635
Median	0.272470	96.10000	6.787316	35.39036	27.28100
Maximum	0.321258	100.0000	9.540480	40.20875	37.34000
Minimum	0.215774	78.40000	2.865413	22.67429	20.25700
Std. Dev.	0.028547	5.748656	1.399387	4.495348	5.289959
Skewness	-0.055560	-1.013609	-0.226784	-1.002409	0.249353
Kurtosis	2.191584	3.386133	3.654157	3.243956	1.797666
Jarque-Bera	0.860099	4.258711	0.818457	5.268463	2.188490
Probability	0.650477	0.118914	0.664162	0.071774	0.334792
Sum	8.366041	2263.870	209.2648	1059.966	862.3070
Sum Sq. Dev.	0.024448	760.0821	58.74849	606.2445	839.5100
Observations	31	24	31	31	31

In terms of distribution, most variables are approximately normal, with Jarque-Bera test probabilities above 0.05, confirming suitability for regression modelling. Overall, the descriptive statistics confirm that Vietnam’s dataset is characterized by rising electricity access and urbanization, both of which are closely tied to increasing CO₂ emissions efficiency challenges.

4.1 Stationarity Testing (Augmented Dickey-Fuller Test)

Before applying time-series regression techniques, it is essential to verify whether the variables are stationary. Stationarity ensures that the mean and variance of a series remain constant over time, a key requirement for most econometric models. To test for unit roots, several standard tests were employed: Levin, Lin & Chu (LLC), Im, Pesaran and Shin (IPS), ADF-Fisher, and PP-Fisher tests.

Table 3. Stationary testing

Method	Statistic	Prob.**	Cross-sections	Obs
Null: Unit root (assumes common unit root process)				
Levin, Lin & Chu t*	-0.96560	0.1671	2	60
Null: Unit root (assumes individual unit root process)				
Im, Pesaran and Shin W-stat	0.46056	0.6774	2	60
ADF - Fisher Chi-square	1.75372	0.7809	2	60
PP - Fisher Chi-square	0.95450	0.9166	2	60

** Probabilities for Fisher tests are computed using an asymptotic Chi- square distribution. All other tests assume asymptotic normality.

The results from the group unit root tests (Levin, Lin & Chu t*, Im, Pesaran and Shin W-stat, ADF-Fisher, and PP-Fisher) indicate that CO₂ emissions relative to GDP are non-stationary, since all p-values exceed the 0.05 threshold. For example, the Levin, Lin & Chu test yields a p-value of 0.1671, meaning the null hypothesis of a unit root cannot be rejected. This confirms the presence of non-stationarity, making it necessary to change the series before applying regression-based models such as ARIMA and ARDL.

4.2 Differencing the Data

To address non-stationarity, the first difference of the CO₂ emissions series (denoted D_CO₂) was computed and tested again using the Augmented Dickey-Fuller (ADF) test. The differenced series is expected to stabilize the mean and variance of the data over time.

The Augmented Dickey-Fuller (ADF) test on the differenced CO₂ series (D(CO₂)) produces a t-statistic of -4.947 and a p-value of 0.0004, which is well below 0.05. This allows us to reject the null hypothesis of a unit root, confirming that the differenced series is stationary. The model diagnostics show an R-squared of 0.54, suggesting a reasonable fit, while the Durbin-Watson statistic of 2.10 indicates no serious autocorrelation problem. By achieving stationarity, the data becomes suitable for regression analysis, ensuring valid and unbiased estimation in subsequent models.

Table 4. Differencing the data

	t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic	-4.947487	0.0004
Test critical values: 1% level	-3.689194	
5% level	-2.971853	
10% level	-2.625121	

*MacKinnon (1996) one-sided p-values.

Augmented Dickey-Fuller Test Equation

Dependent Variable: D(D_CO2)

Method: Least Squares

Date: 10/18/24 Time: 07:20

Sample (adjusted): 1993 2020

Included observations: 28 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
D_CO2(-1)	-1.253053	0.253271	-4.947487	0.0000
D (D_CO2(-1))	0.310852	0.189259	1.642470	0.1130
C	0.003841	0.002906	1.321712	0.1982
R-squared	0.542055	Mean dependent var		0.000197
Adjusted R-squared	0.505420	S.D. dependent var		0.021265
S.E. of regression	0.014955	Akaike info criterion		-5.466618
Sum squared resid	0.005591	Schwarz criterion		-5.323881
Log likelihood	79.53265	Hannan-Quinn criter.		-5.422982
F-statistic	14.79588	Durbin-Watson stat		2.102020
Prob (F-statistic)	0.000058			

4.3 Linear Trend Model

A simple linear trend model was estimated to evaluate whether there is a significant deterministic trend in the differenced CO₂ emissions series over time.

Table 5. Linear Trend Model

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.000536	0.005814	0.092241	0.9272
@TREND	0.000112	0.000327	0.341842	0.7350
R-squared	0.004156	Mean dependent var		0.002272
Adjusted R-squared	-0.031410	S.D. dependent var		0.015287
S.E. of regression	0.015526	Akaike info criterion		-5.428313
Sum squared resid	0.006749	Schwarz criterion		-5.334900
Log likelihood	83.42469	Hannan-Quinn criter.		-5.398429
F-statistic	0.116856	Durbin-Watson stat		1.810763
Prob (F-statistic)	0.735022			

$R^2 = 0.004$, F-statistic = 0.117, Prob (F) = 0.735.

4.4 Autoregressive Model (AR)

To assess the influence of past emissions on current levels, an autoregressive (AR) model of order three was estimated. The model specification is as follows:

$$CO2_t = \alpha_0 + \alpha_1 CO2_{t-1} + \alpha_2 CO2_{t-2} + \alpha_3 CO2_{t-3} + \varepsilon_t$$

The AR(3) model shows a good fit with R-squared = 0.746, and the first lag (AR(1)) is highly significant, meaning past CO₂ emissions strongly predict current levels. Residual variance is very small (SIGMASQ = 0.000201), and the Durbin-Watson statistic (1.95) suggests no autocorrelation. This confirms that Vietnam's CO₂ emissions are highly persistent, with recent emissions trends driving current patterns. However, because the AR model only uses past values of emissions and excludes explanatory variables, it provides limited policy insights.

Table 6. ARMA Model

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.271143	0.019070	14.21827	0.0000
AR(1)	1.072615	0.193336	5.547945	0.0000
AR(2)	-0.395299	0.269252	-1.468137	0.1541
AR(3)	0.186504	0.251091	0.742775	0.4643
SIGMASQ	0.000201	6.19E-05	3.241862	0.0032
R-squared	0.745616	Mean dependent var		0.269872
Adjusted R-squared	0.706480	S.D. dependent var		0.028547
S.E. of regression	0.015466	Akaike info criterion		-5.303966
Sum squared resid	0.006219	Schwarz criterion		-5.072678
Log likelihood	87.21147	Hannan-Quinn criter.		-5.228572
F-statistic	19.05193	Durbin-Watson stat		1.952730
Inverted AR Roots	.86	.10+.45i		.10-.45i



Figure 1. Actual, Fitted and Residual line of CO₂ ARMA model

4.5 Autoregressive Integrated Moving Average (ARIMA) Model (1,1,2)

An ARIMA(1,1,2) model was estimated on the differenced CO₂ emissions to capture time-dependent patterns using both autoregressive and moving average terms. The model is specified as:

$$\Delta CO2_t = \varphi \Delta CO2_{t-1} + \theta_1 \varepsilon_{t-1} + \theta_2 \varepsilon_{t-2} + \varepsilon_t$$

The ARIMA(1,1,2) results (Table 7) show a statistically significant constant term, but the AR and MA coefficients are insignificant, with unusually large standard errors. R-squared is low (0.27), and residual diagnostics suggest instability. Although the Durbin-Watson statistic (1.94) indicates no autocorrelation, the weak explanatory power and estimation issues limit reliability.

Table 7. ARMA Maximum Likelihood

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.002413	0.000686	3.519077	0.0017
AR (1)	0.410652	0.422550	0.971843	0.3404
MA (1)	-0.553336	2153.166	-0.000257	0.9998
MA (2)	-0.446664	2657.773	-0.000168	0.9999
SIGMASQ	0.000166	0.116014	0.001427	0.9989
R-squared	0.266951	Mean dependent var		0.002272
Adjusted R-squared	0.149663	S.D. dependent var		0.015287
S.E. of regression	0.014097	Akaike info criterion		-5.453194
Sum squared resid	0.004968	Schwarz criterion		-5.219662
Log likelihood	86.79792	Hannan-Quinn criter.		-5.378485
F-statistic	2.276032	Durbin-Watson stat		1.936572
Prob(F-statistic)	0.089401			
Inverted AR Roots	.41			
Inverted MA Roots	1.00		-.45	

This model was therefore not chosen as the primary tool for policy analysis, because it captures short-run dynamics but fails to link emissions to key structural drivers (GDP, electricity

access, industrialization, urbanization). In other words, ARIMA forecasts emissions trends but cannot explain why emissions rise or fall, making it unsuitable for policy guidance in this study.

4.6 Autoregressive Distributed Lag (ARDL) Model (1,1,1,1,1)

The ARDL model explains 63% of variation in emissions ($R^2 = 0.63$), though the adjusted R^2 is lower (0.37). Short-run coefficients (D-terms) are mostly insignificant, suggesting that immediate changes in GDP, electricity access, and industrial output have weak short-term effects on emissions.

Table 8. ARDL Model

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.277963	0.181753	1.529350	0.1501
D(ELC)	-0.002999	0.002817	-1.064888	0.3063
D(GDP)	0.005512	0.003467	1.589955	0.1359
D(IND)	-0.003547	0.002724	-1.302074	0.2155
D(URB)	-0.033826	0.186250	-0.181617	0.8587
CO ₂ (-1)	-0.221192	0.223497	-0.989687	0.3404
ELC(-1)	-0.005326	0.002704	-1.969441	0.0706
GDP(-1)	0.000114	0.004888	0.023280	0.9818
IND(-1)	0.002793	0.002328	1.199782	0.2516
URB(-1)	0.007213	0.002998	2.406307	0.0317
R-squared	0.627593	Mean dependent var		0.002641
Adjusted R-squared	0.369772	S.D. dependent var		0.016369
S.E. of regression	0.012995	Akaike info criterion		-5.549462
Sum squared resid	0.002195	Schwarz criterion		-5.055769
Log likelihood	73.81881	Hannan-Quinn criter.		-5.425300
F-statistic	2.434225	Durbin-Watson stat		2.437222
Prob (F-statistic)	0.070680			

However, long-run effects are more meaningful: lagged electricity access (ELC(-1)) is marginally significant and negative, while lagged urbanization (URB(-1)) is significant and positive. This indicates that improving electricity access reduces emissions intensity over time, while urbanization increases it.

This ARDL model is considered the main result of the study, since it incorporates both short- and long-run dynamics and directly links economic drivers to emissions efficiency. Importantly, it shows that urbanization without sustainable planning worsens emissions, while better electricity access (e.g., renewables) improves efficiency.

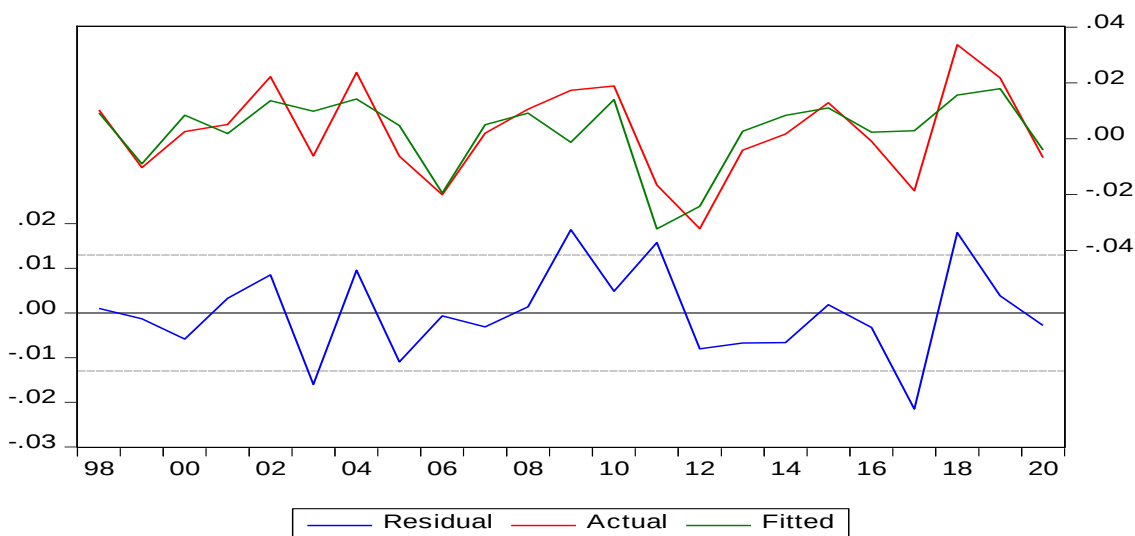


Figure 2. Actual, Fitted and Residual line in ARDL Model

5 Conclusion and policy recommendations

The objective of this study was to investigate the drivers of CO₂ emissions efficiency in Vietnam, focusing on the relationship between economic growth, industrial output, electricity access, and urbanization. Using annual data from 1990 to 2020, the analysis applied multiple econometric techniques, including AR, ARIMA, and ARDL models, with the ARDL model identified as the most policy-relevant because it captures both short- and long-run dynamics.

The empirical results show that short-run effects of GDP, industrial output, electricity access, and urbanization are not statistically significant, while the long-run results reveal two critical findings: (i) electricity access (ELC(-1)) has a marginally significant negative impact on emissions intensity, suggesting that expanded access, particularly through renewable sources, can enhance efficiency; and (ii) urbanization (URB(-1)) has a significant positive impact, indicating that unchecked urban growth increases emissions intensity. These results highlight the

dual challenge facing Vietnam: how to expand electricity access sustainably while managing the environmental pressures of rapid urbanization.

The policy implications follow directly from these findings. Vietnam should strengthen investments in renewable energy to ensure that greater electricity access continues to reduce emissions intensity in the long run. At the same time, urbanization must be guided by sustainable planning—through stricter building codes, low-emission public transport, and green infrastructure—to counteract its significant positive impact on emissions. Industrial policies should also encourage adoption of cleaner technologies to reduce emissions persistence observed in the AR and ARDL models. By aligning these policies, Vietnam can decouple economic growth from carbon emissions, supporting its transition toward a low-carbon, sustainable future.

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