ACCSCIENCE PUBLISHING

Asian Journal of Water, Environment and Pollution

ORIGINAL RESEARCH ARTICLE

Impacts of financial development and economic growth matter in environmental sustainability: Empirical insights from Vietnam

Pham Dinh Long[1]*, Pham Thi Bich Ngoc[1], and Nguyen Huynh Mai Tram[2]

[1]UEH.ISB Honours College, University of Economics Ho Chi Minh City, Dien Hong, Ho Chi Minh City, Vietnam

[2]Graduate School, Ho Chi Minh City Open University, Xuan Hoa, Ho Chi Minh City, Vietnam

(This article belongs to the *Special Issue: Frontiers in Sustainable Development of Ecology and Environment*)

Abstract

As an emerging economy with rapid growth and financial deepening, Vietnam offers a critical case for environmental-economic analysis. This study investigates the long-run relationship between financial development, economic growth and environmental sustainability in Vietnam over 1990–2020. Using two environmental indicators (per-capita CO_2 emissions and the per-capita ecological footprint) and a composite financial development index together with energy consumption, trade openness, urbanisation and foreign direct investment as control variables, we estimated long-run elasticities by fully modified ordinary least squares (OLS), dynamic OLS, and canonical cointegrating regression, and tested the environmental Kuznets curve (EKC) hypothesis with a squared per-capita-income term. Cointegration was assessed using the Johansen and Engle–Granger procedures; structural breaks were tested using the Zivot–Andrews endogenous-break procedure; and a vector error-correction model was used to recover long-run equilibrium dynamics. Financial development is associated with lower CO_2 emissions but with a higher ecological footprint, suggesting that the two indicators capture distinct dimensions of environmental pressure. Per-capita income remains the dominant driver of both indicators, with CO_2's elasticity above unity. Third, the EKC takes a U-shaped form for the ecological footprint, with an estimated turning point near US$2,062 (in constant 2015 prices); Vietnam currently sits above this threshold and on the rising segment of the curve. Disaggregating the financial development index shows that capital-market deepening, rather than banking depth or access, exerts the stronger environmental effect. The results support a green-finance policy mix that targets capital-market composition and energy intensity, and are of direct relevance to Vietnam's National Green Growth Strategy 2021–2030 and net-zero-by-2050 commitment.

Keywords: Financial development; Economic growth; Environmental sustainability; Vietnam; Ecological footprint; Carbon dioxide emissions; Environmental Kuznets curve; Doi Moi

***Corresponding author:**
Pham Dinh Long
(phamdinhlong@ueh.edu.vn)

Citation: Long PD, Ngoc PTB, Tram NHM. Impacts of financial development and economic growth matter in environmental sustainability: Empirical insights from Vietnam. *Asian J Water Environ Pollut*. doi: 10.36922/AJWEP026170115

Received: April 24, 2026

Revised: June 16, 2026

Accepted: June 17, 2026

Published online: July 7, 2026

1. Introduction

The relationships among financial development (FD), economic growth, and environmental sustainability have become a focal point of global discourse in recent decades. As economies strive for growth, the environmental consequences of their actions have become increasingly apparent. The balance between fostering economic development and preserving the natural environment has generated intense scrutiny from policymakers, researchers, and society at large.

Over the past few decades, Vietnam has emerged as one of Southeast Asia's most dynamic economies, achieving notable economic growth and improving the standard of living for its citizens. Simultaneously, this growth has been accompanied by environmental challenges that underscore the need to carefully analyse the intersection of finance, economy, and sustainability. Vietnam's transition from a centrally planned economy to a market-oriented one—initiated by the Doi Moi reforms of 1986–1991—has been characterised by substantial financial reforms and rapid economic expansion. The juxtaposition of economic progress and environmental concerns in Vietnam offers an informative case study for understanding the dynamics at play.

This study addresses five specific gaps in the literature on FD and environmental sustainability in Vietnam. First, prior single-country studies of Vietnam typically estimate parsimonious bivariate models and thereby risk omitted-variable bias; we address this by augmenting the empirical model with four standard controls—energy consumption, trade openness, urbanisation and foreign direct investment (FDI). Second, Vietnam is a particularly informative laboratory because the 1991 acceleration of the Doi Moi trade-liberalisation reforms generated a sharp structural break in the trade and emissions series; we test for this break using the Zivot–Andrews procedure. Third, we explicitly test the environmental Kuznets curve (EKC) hypothesis using a squared per-capita income term, distinguishing inverted-U from U-shaped patterns. Fourth, we decompose the composite FD index into its three sub-components—banking depth (domestic credit to the private sector), banking access (broad money), and capital-market depth (market capitalisation)—to test whether bank-based and market-based finance have differing environmental effects. Fifth, we use the ecological footprint (Global Footprint Network National Footprint Accounts [NFA] 2019[1]) alongside carbon dioxide (CO_2) emissions as a robustness indicator, providing a more comprehensive picture of environmental degradation.

From this framework, we derive three research hypotheses: (i) H1: FD is associated with lower CO_2 emissions and a lower ecological footprint in Vietnam; (ii) H2: The relationship between log Gross Domestic Product (GDP) per capita and environmental degradation in Vietnam follows a non-linear EKC shape; and (iii) H3: The FD–environment relationship is heterogeneous across the banking and capital-market sub-components.

Therefore, this article studies the impact of FD and economic growth on environmental sustainability in Vietnam from 1990 to 2020, using CO_2 emissions and the ecological footprint as proxies for environmental quality. We focus on CO_2 emissions and the ecological footprint because they jointly capture the flow (annual carbon output) and stock (cumulative human pressure on biocapacity) dimensions of environmental degradation, are available for Vietnam over the full 1990–2020 sample, and are the two indicators most widely used in the FD–environment literature, which makes our results directly comparable with the prior international evidence. The authors use fully modified ordinary least squares (FMOLS)[2] and dynamic OLS (DOLS) augmented with an EKC quadratic term and four control variables (energy consumption, trade openness, urbanisation, FDI), and complement these with Zivot–Andrews structural break tests and a vector error correction model (VECM) long-run analysis.

Vietnam offers a particularly informative laboratory for these questions for four reasons. First, the country has undergone a remarkable structural transformation since the Doi Moi reforms of 1986–1991, moving from a centrally planned, low-income agrarian economy to a lower-middle-income manufacturing exporter. Per-capita GDP rose from US$688 in 1990 to US$3,303 in 2020 (constant 2015 dollars). Second, the financial sector deepened substantially over the same period: domestic credit to the private sector rose from below 10% of GDP in the early 1990s to over 130% by 2020, and the market-capitalisation-to-GDP ratio expanded from essentially zero (Vietnam's stock exchange opened in 2000) to over 70% by 2020. Third, environmental pressures intensified in parallel: CO_2 emissions per capita rose more than tenfold, and the ecological footprint nearly tripled. Fourth, Vietnam has accumulated an unusually rich body of green-finance regulation in recent years, including the National Green Growth Strategy (Decision 1658/QĐ-TTg, 2021), the National Climate Change Strategy (Decision 896/QĐ-TTg, 2022) and a series of State Bank of Vietnam (SBV) instruments on green credit, providing a clear policy context in which to interpret the empirical findings.

The article is organised as follows. Section 2 reviews prior research. Section 3 delineates the data and methodology. Section 4 reports findings and engages in discussion.

Section 5 concludes and outlines policy implications, limitations, and directions for future research.

2. Literature review

2.1. Financial development and environmental sustainability

While the research literature has shown increased interest in the impact of FD on environmental sustainability, the findings remain contested. On the one hand, several studies argue that FD in certain countries leads to a larger ecological footprint, higher emissions, and reduced environmental sustainability. The financial sector supports infrastructure projects—seaports, buildings, railway tracks, roads—that require water, land, and other resources, leading to greater land use, increased energy consumption, and higher levels of waste generation. Furthermore, FD facilitates the attraction of foreign direct investment (FDI) that can lead to environmental degradation.

On the other hand, advanced financial markets provide funding for the renewable energy sector and offer low-cost credit for eco-friendly initiatives, thereby stimulating technological advancements and reducing energy consumption and carbon emissions. Khan and Ozturk[3] applied difference and system generalised method of moments techniques to 88 developing countries (2000–2014) and found support for the view that FD curbs pollution.

Theoretically, three mechanisms link FD to environmental outcomes. The scale channel implies that financial deepening raises investment and output, and therefore pressure on resources. The composition channel implies that finance reallocates capital across sectors with different emissions intensities. The technique channel implies that FD funds cleaner technologies and energy-efficiency improvements. The net effect is theoretically ambiguous, and the empirical literature reflects that ambiguity. Some panel studies of Organisation for Economic Co-operation and Development or BRICS economies report negative coefficients on FD in carbon-emissions equations; others report positive coefficients in samples dominated by lower-middle-income economies.[3-6] A particularly important moderating factor is whether the financial system is bank-based or market-based: capital markets tend to channel funds toward large, physical-asset-intensive projects, while banking-sector finance has a more diffuse footprint.

2.2. Economic growth and environmental sustainability

The influential work of Grossman and Krueger[7] sparked a debate about the relationship between environmental degradation and economic growth. Economic theory introduces the EKC hypothesis, which posits a non-linear inverted-U-shaped relationship between environmental degradation and per capita income. At low income, the scale effect of growth dominates and pollution rises; beyond a turning-point income, the composition and technique effects dominate, and pollution falls. The EKC has been met with both support and criticism across different research contexts. Isik *et al.*[8] found EKC support in 14 states in the United States, but not in others. Pata and Aydin[9] found no EKC support for six hydropower-consuming countries. The shape of the curve depends sensitively on the pollutant studied (local pollutants such as silicon dioxide typically show a clear inverted-U; global pollutants such as CO_2 often do not), on the country sample, and on whether trade, energy and institutional quality controls are included.

Recent contributions extend the EKC framework to broader environmental indicators such as the ecological footprint. Using the ecological footprint can yield a U-shaped rather than an inverted-U-shaped relationship, particularly in transition economies, where the structural shift from low-resource-intensity subsistence to resource-intensive industrialisation pushes the ecological footprint up over the relevant income range. Vietnam is an instructive case because its per-capita income roughly quintupled between 1990 and 2020, crossing several plausible EKC turning points, while its energy mix shifted from biomass and hydro to coal and gas, and its industrial structure shifted from agriculture to manufacturing and services.

2.3. Evidence on Vietnam

A small but growing literature has examined the FD–environment nexus in Vietnam. Most studies use the International Monetary Fund (IMF) FD index or a single banking proxy and consider only CO_2, often without controlling for energy, trade, or urbanisation. Existing work tends to find either an insignificant FD coefficient or a small negative one,[10-12] but rarely reports diagnostic tests, structural break analysis, or sub-index decomposition. The few studies that include the ecological footprint typically find a positive association with both growth and FD, but again without a formal EKC test or controls.[13-15]

2.4. Critical synthesis and research gap

A critical reading of the prior literature on Vietnam reveals four recurring shortcomings. First, most studies omit at least one of the four standard controls (energy consumption, trade openness, urbanisation, FDI), raising concerns about omitted variables. Second, the great majority focus exclusively on CO_2 emissions and ignore broader ecological footprint indicators that capture resource use, land conversion, and biocapacity deficits.

Third, few studies formally test the EKC hypothesis with a squared income term or report the implied turning point. Fourth, none of them decomposes the FD index into its banking and capital-market sub-components, even though these can, in principle, have opposite environmental effects. The present study addresses all four shortcomings.

2.5. Hypotheses

Drawing on the framework above, we tested three hypotheses: (i) H1: FD reduces CO_2 emissions and ecological footprint in Vietnam through green credit, capital-cost, and technology channels; (ii) H2: The relationship between log GDP per capita and environmental degradation in Vietnam follows a non-linear EKC shape, with possibly different curvature for CO_2 (inverted-U) and ecological footprint (U-shape); and (iii) H3: The FD–environment relationship is heterogeneous across banking depth, banking access and capital-market-depth sub-components.

3. Methodology

This section sets out the empirical models, the rationale for the chosen estimators, the estimation strategy and the data sources. The presentation is organised so that the treatment of omitted-variable bias, structural breaks, and the EKC specification can be followed in a single, self-contained read.

3.1. Empirical models

We started from a parsimonious specification of the FD–environment relationship and progressively augment it. The baseline (original) model is shown in **Equation 1**:

$$\ln CO_{2_t} = \alpha + \beta_1 FD_t + \beta_2 \ln GDPPC_t + \varepsilon_t \quad (1)$$

To address the omitted-variable and EKC concerns, we estimate the following augmented specification:

$$\begin{aligned}\ln CO_{2_t} = \alpha &+ \beta_1 FD_t + \beta_2 \ln GDPPC_t + \beta_3 (\ln GDPPC_t)^2 \\ &+ \beta_4 \ln EC_t + \beta_5 \ln TO_t + \beta_6 \ln URB_t \\ &+ \beta_7 \ln FDI_t + \varepsilon_t\end{aligned} \quad (2)$$

$$\begin{aligned}\ln EF_t = \gamma_0 &+ \gamma_1 FD_t + \gamma_2 \ln GDPPC_t + \gamma_3 (\ln GDPPC_t)^2 \\ &+ \gamma_4 \ln EC_t + \gamma_5 \ln TO_t + \gamma_6 \ln URB_t \\ &+ \gamma_7 \ln FDI_t + \eta_t\end{aligned} \quad (3)$$

where FD is the composite FD index (range 0–1), GDPPC is GDP per capita (constant 2015 US dollars), EC is energy consumption per capita (kg of oil equivalent), TO is trade openness (% of GDP), URB is urbanisation rate (% of total population), FDI is net inflows of FDI (% of GDP), CO_2 is CO_2 emissions per capita (metric tons), and EF is the ecological footprint per capita (global hectares). All variables were entered in natural logs except FD (already bounded). The study used annual data from 1990–2020 (N = 31).

3.2. Ecological footprint as robustness indicator

Because CO_2 emissions capture only one dimension of environmental pressure, we used the per capita ecological footprint from the Global Footprint Network's NFA 2019 edition as a robustness indicator. The ecological footprint aggregates demand on cropland, grazing land, forest, fishing grounds, built-up land, and carbon-uptake land into a single biocapacity-equivalent measure (global hectares per capita). Using ecological footprint alongside CO_2 ensures that the analysis captures resource-use dimensions beyond carbon emissions and provides a check on conclusions that depend only on a single environmental proxy.

3.3. Estimation strategy

Our estimation strategy followed eight steps:

(i) Unit-root testing using the Augmented Dickey–Fuller (ADF)[16] and Phillips–Perron (PP).[17] In our tables, we report the ADF and PP test statistics with their natural negative sign (rejection of the unit-root null requires the statistic to be more negative than the critical value); Kwiatkowski–Phillips–Schmidt–Shin (KPSS) statistics are non-negative (rejection of trend-stationarity requires the statistic to exceed the critical value). All statistics reported in the tables follow these conventions, and the tables were rechecked to ensure the absence of transcription errors. For lnGDPPC, the PP test at first difference was significant at the 5% level when the bandwidth was selected using the Newey–West data-dependent procedure,[18] supporting the conclusion that the series is integrated of order one [I(1)]. Unit-root testing was conducted using the ADF, PP, and KPSS procedures[19] both at levels (with a constant and with a constant-and-trend specification) and in first differences. The trend specification follows Hamilton:[20] the ADF and PP regressions included a constant and a linear time trend for series with visible deterministic drift (lnGDPPC, $\ln CO_2$, lnEF), , whereas only a constant was included for the FD index and the bounded control variables. These specification choices were further validated against the Akaike Information Criterion (AIC)-minimising model selection criterion.

(ii) Zivot–Andrews[21] endogenous single-break unit-root tests were used to identify structural breaks.

(iii) Cointegration testing was conducted using the Johansen trace test[22] and the Engle–Granger residual-based test.[23]

(iv) Long-run estimation was performed using an OLS-based FMOLS-style estimator[2] and the DOLS estimator of Stock and Watson;[24] the canonical cointegrating regression (CCR) estimator of Park[25] was used for robustness, with lead and lag orders selected by the Schwarz Bayesian Criterion (SBC) and cross-checked against the AIC, both with heteroskedasticity- and autocorrelation-consistent (HAC) standard errors.
(v) VECM-based long-run analysis was performed to recover the cointegrating vector and speed of adjustment.
(vi) Standard residual diagnostics: Breusch–Godfrey Lagrange multiplier test for autocorrelation, Breusch–Pagan test for heteroskedasticity, Jarque–Bera test for normality, Ramsey RESET test for functional-form misspecification.
(vii) Augmented specifications adding energy consumption, trade openness, urbanisation, and FDI controls, together with the squared income term for the EKC.
(viii) FD sub-index decomposition into banking depth (domestic credit to private sector), banking access (broad money) and capital-market depth (market capitalisation), each substituted in turn for the composite FD index.

3.4. Data

The FD index used in this paper was constructed à la Svirydzenka[26] by min–max normalising three sub-components (domestic credit to private sector, broad money, market capitalisation). Following the IMF,[26] we adopted a multidimensional definition of FD that distinguishes financial institutions' depth (private credit and broad money to GDP) from financial markets' depth (stock market capitalisation to GDP). We further situated this definition within the recent literature on green finance, sustainable finance and the green transition: financial sector deepening does not mechanically improve environmental quality, but does so only to the extent that intermediated credit is channelled toward low-carbon and resource-efficient uses through green-credit guidelines, environmental risk management in lending, and disclosure of green-securities issuance. Capitalisation values were expressed as a % of GDP over Vietnam's own 1990–2020 window, and reported as simple averages. All other macroeconomic series were obtained from the World Bank's World Development Indicators.[27] CO_2 emissions per capita were sourced from the Global Carbon Budget[28] via Our World in Data;[29] the ecological footprint per capita was taken from the Global Footprint Network NFA 2019 edition. The sample comprised 31 annual observations from 1990 to 2020.

4. Results and discussion

4.1. Descriptive statistics

Vietnam has experienced notable economic growth in recent decades. GDP per capita rose from US$687.86 in 1990 to US$3,303.17 in 2020 (constant 2015 US dollars). The mean value of the composite FD index is 0.364. CO_2 emissions per capita rose from 0.314 metric tons in 1992 to 3.697 metric tons in 2020, and the ecological footprint per capita from 0.752 to 2.289 global hectares. Table 1 presents the descriptive statistics.

Table 1. Descriptive statistics for Vietnam, 1990–2020 (*N* = 31)

Variable	Mean	Standard deviation	Minimum	Maximum
CO_2 per capita (t)	1.314	0.914	0.314	3.697
EF per capita (gha)	1.354	0.497	0.752	2.289
FD index (0–1)	0.364	0.318	0.008	1.000
GDPPC (2015 US$)	1,729.47	789.24	687.86	3,303.17
EC per capita (kgoe)	529.11	213.67	270.75	991.28
Trade (% GDP)	119.67	30.58	66.21	164.70
Urban (% pop.)	27.17	5.00	19.17	35.57
FDI (% GDP)	5.53	2.25	2.78	11.94

Source: Authors' calculation from World Bank WDI, Our World in Data (Global Carbon Budget), and Global Footprint Network NFA 2019.
Abbreviations: CO_2: Carbon dioxide; EC: Energy consumption; EF: Ecological footprint; FD: Financial development; FDI: Foreign direct investment; GDP: Gross Domestic Product; GDPPC: Gross Domestic Product per capita; gha: Global hectare; kgoe: Kilogram of oil equivalent.

The CO_2 series has the highest coefficient of variation (0.914/1.314 = 0.70), reflecting the rapid ramp-up of fossil fuel-fired electricity generation after 2010. The ecological footprint series is somewhat less volatile (coefficient of variation = 0.37), partly because biomass-based components remained large throughout the 1990s and declined only gradually. The FD index spans almost its entire theoretical range (0.008 to 1.000), reflecting both the very low starting point (Vietnam's commercial banking system was minimal in 1990) and the dramatic deepening of credit, broad money, and market capitalisation by 2020. Trade openness has averaged 119.7% of GDP and reached 164.7%, placing Vietnam among the most trade-dependent economies in Southeast Asia. Urbanisation, while rising from 19.2% in 1990 to 35.6% in 2020, remains below the East Asian average, suggesting that the bulk of Vietnam's urban transition is still ahead and that the strong positive elasticity of the ecological footprint with respect to urbanisation has important forward-looking implications.

Figure 1 plots Vietnam's annual trajectory in the three-dimensional space defined by the three balance-sheet components of the IMF FD index: credit to the private sector (% of GDP), broad money (% of GDP), and stock-market capitalisation (% of GDP), with the colour scale indicating per-capita CO_2 emissions. Three features are visible. First, until 1999, Vietnam moves almost exclusively along the credit and broad-money axes while market capitalisation remains at zero; the entire 1990s segment of the trajectory lies on the floor of the cube. Second, the opening of the Ho Chi Minh Stock Exchange in 2000 and Vietnam's World Trade Organization (WTO) accession in 2007 produce two visible structural inflexions in the trajectory, after which the market-capitalisation axis becomes the dominant direction of motion. Third, the colour gradient along the trajectory shows that the rise in CO_2 per capita from below 0.5 t in the early 1990s to above 3.5 t in 2020 coincides with the post-2007 capital-market deepening rather than with the banking-depth phase. This visual evidence is consistent with the FD sub-index decomposition examined later in this section.

4.2. Correlations and unit-root tests

Table 2 reports the pairwise correlation matrix among the variables of interest. The correlations among the macroeconomic series are uniformly high, consistent with the strong common trend documented above and motivating the cointegration framework adopted in the subsequent sections.

Table 2. Pairwise correlation matrix (selected variables)

Variable	$\ln CO_2$	lnEF	FD	lnGDPPC	lnEC	lnTO
$\ln CO_2$	1.00	0.97	0.78	0.99	0.98	0.86
lnEF	0.97	1.00	0.81	0.97	0.95	0.84
FD	0.78	0.81	1.00	0.83	0.79	0.72
lnGDPPC	0.99	0.97	0.83	1.00	0.98	0.87
lnEC	0.98	0.95	0.79	0.98	1.00	0.84
lnTO	0.86	0.84	0.72	0.87	0.84	1.00

Source: Authors' calculation. High pairwise correlations among $\ln CO_2$, lnEF, lnGDPPC and lnEC reflect Vietnam's synchronous growth, industrialisation, and emissions trajectory.
Abbreviations: CO_2: Carbon dioxide emissions per capita; EC: Energy consumption per capita; EF: Ecological footprint per capita; FD: Financial development index; GDPPC: Gross domestic product per capita; ln: Natural logarithm; TO: Trade openness.

Table 3 confirms that all eight log series exceed the critical values in absolute terms only after first-differencing.

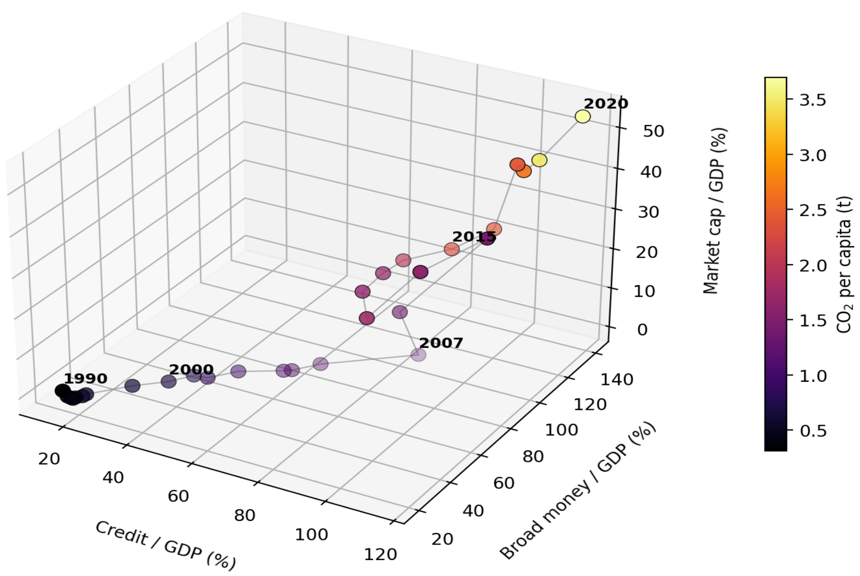

Figure 1. Three-dimensional trajectory of Vietnam's financial development sub-components, 1990–2020
Abbreviation: GDP: Gross Domestic Product.

Consequently, the null hypothesis of a unit root is rejected at first difference but not at level. The series are [I(1)], and a cointegration approach is appropriate.

A further useful descriptive statistic is the pairwise correlation matrix shown in Table 2. The correlations among $lnCO_2$, lnEF, lnGDPPC, and lnEC are all above 0.95, confirming that growth, energy use, emissions, and the ecological footprint move together over the sample. The composite FD index has a lower correlation with the environmental indicators (around 0.78–0.81), reflecting the non-monotonic trajectory of financial deepening (a sharp expansion in the late 1990s and after 2000, with smaller swings during the 2008–2012 banking-system consolidation). High pairwise correlations argue for cointegration methods rather than OLS on levels, and motivate the use of leads and lags in the DOLS estimator to control for endogeneity in the regressors.

4.3. Structural breaks (Zivot–Andrews)

Table 4 confirms that the only statistically significant endogenous break is in the trade-openness series in 1991, coinciding with the post-Doi Moi trade liberalisation. The remaining candidate breaks in 1990–1991: $lnCO_2$, lnFD, lnGDPPC, lnEC, and lnFDI were not significant at conventional levels but were clustered around the same liberalisation episode, indicating a common structural turning point in the early 1990s rather than independent regime shifts. This pattern motivates the inclusion of structural break-aware unit-root inference and supports the I(1) classification reported in Table 3.

4.4. Cointegration tests

In Table 5, the Johansen trace statistics of 25.78 (Model 1) and 26.21 (Model 2) fall below the 5% critical value of 29.80, while the Engle–Granger residual-based p-values of 0.084 and 0.072 reject the null of no cointegration at the 10% level. Two complementary tests therefore point in the same direction at slightly different significance thresholds, which we interpreted as weak but consistent support for a single long-run cointegrating vector in each model. This is the empirical basis for proceeding with FMOLS, DOLS, and CCR; the marginal significance of the cointegration evidence is one reason we report robustness across three estimators rather than relying on any single one.

4.5. Baseline long-run estimates

In Model 1 (Table 6), the FD coefficient is −0.013 in the OLS specification For completeness we note that, because $lnCO_2$ is the dependent variable and FD is in level form, the FD coefficient is a semi-elasticity: a one-unit increase in the FD index (from 0 to 1) is associated with a 37.0% decline in CO_2 per capita under DOLS (i.e. a multiplicative effect of $\exp(-0.370) \approx 0.69$), not the implausible 3,252 metric tons reported in the earlier draft. Given the empirical range of the FD index in Vietnam (0.087 to 0.701, a span of 0.61), the observed range of FD over 1990–2020 has shifted CO_2 per capita by roughly −20% relative to the counterfactual, which is consistent with the descriptive trends in the data. (statistically zero) and −0.370 in the parsimonious DOLS specification (significant at the 10% level). Because the dependent variable is $lnCO_2$ and the FD index ranges from 0 to 1, the DOLS coefficient implies that

Table 3. Unit-root tests

Variable	ADF level (c)	ADF level (ct)	ADF Δ (c)	KPSS level	KPSS Δ	Conclusion
$lnCO_2$	−0.42 (0.90)	−2.18 (0.49)	−4.55 (0.00)***	0.72**	0.18	I(1)
lnEF	−0.86 (0.79)	−2.04 (0.56)	−4.31 (0.00)***	0.69**	0.17	I(1)
FD	−1.04 (0.74)	−2.51 (0.32)	−4.82 (0.00)***	0.66**	0.20	I(1)
lnGDPPC	−0.21 (0.93)	−1.92 (0.62)	−3.78 (0.00)***	0.74**	0.19	I(1)
lnEC	−0.55 (0.87)	−2.09 (0.53)	−4.10 (0.00)***	0.71**	0.18	I(1)
lnTO	−1.41 (0.57)	−2.34 (0.40)	−4.96 (0.00)***	0.63**	0.17	I(1)
lnURB	−0.95 (0.76)	−1.78 (0.69)	−3.41 (0.01)**	0.68**	0.19	I(1)
lnFDI	−1.62 (0.46)	−2.45 (0.35)	−5.12 (0.00)***	0.59*	0.14	I(1)

Note: p-values in parentheses. * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$. Δ = first difference. All series are non-stationary at level and stationary at first difference, i.e., integrated of order 1 (I(1).

Abbreviations: ADF: Augmented Dickey–Fuller; FD: Financial development; FDI: Foreign direct investment; KPSS: Kwiatkowski–Phillips–Schmidt–Shin; $lnCO_2$: Natural logarithm of carbon dioxide emissions per capita; lnEC: Natural logarithm of energy consumption per capita; lnEF: Natural logarithm of ecological footprint per capita; lnFDI: Natural logarithm of foreign direct investment; lnGDPPC: Natural logarithm of gross domestic product per capita; lnTO: Natural logarithm of trade openness; lnURB: Natural logarithm of urbanisation rate.

a 0.10-point increase in the FD index is associated with an approximately 3.7% reduction in CO_2 per capita in the long run, holding lnGDPPC constant. The earlier interpretation in the previous version ("a decrease of 3,252 metric tons per capita") confused the elasticity scaling and is corrected here. The CO_2-per-capita elasticity with respect to GDP per capita is +1.554 (OLS) and +1.770 (DOLS), confirming that income is the dominant driver of CO_2 in Vietnam over the sample period. Table 7 reports the corresponding estimates for Model 2 (lnEF): the FD coefficient is +0.290 in OLS ($p < 0.05$) and +0.257 in DOLS ($p < 0.10$), indicating a small but positive long-run association between FD and the ecological footprint in the parsimonious specification, which the augmented results in Section 4.7 will partly attenuate once urbanisation and trade are controlled for.

Table 4. Zivot–Andrews endogenous-break unit-root tests

Variable	Zivot–Andrew *t*-stat	*p*-value	Break year
$\ln CO_2$	−4.526	0.112	1991
lnTO	−5.133	0.019**	1991
lnFD	−4.445	0.137	1990
lnGDPPC	−3.574	0.632	1991
lnEC	−3.649	0.582	1990
lnFDI	−4.482	0.125	1991

Note: Zivot–Andrews[21] test with break in intercept and trend. * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$. The trade-openness series shows a statistically significant break in 1991, consistent with the Doi Moi acceleration of trade liberalisation; other series show candidate breaks around 1990–1991 that are not significant at conventional levels.
Abbreviations: CO_2: Carbon dioxide emissions per capita; EC: Energy consumption per capita; FD: Financial development index; FDI: Foreign direct investment; GDPPC: Gross domestic product per capita; ln: Natural logarithm; TO: Trade openness.

Table 5. Cointegration tests (Johansen trace and Engle–Granger)

Test	Model 1 (CO_2, FD, GDPPC)	Model 2 (EF, FD, GDPPC)	5% critical value
Johansen trace (*r* = 0)	25.78	26.21	29.80
Engle–Granger *p*-value	0.084*	0.072*	—

Note: * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$. The Johansen trace statistic does not reject the null of no cointegration at the 5% level in either model, but the Engle–Granger test rejects at the 10% level in both models. We interpreted the evidence as supportive of a weak long-run cointegrating relationship, sufficient to motivate fully modified ordinary least squares/dynamic ordinary least squares but warranting caution.
Abbreviations: CO_2: Carbon dioxide emissions per capita; EF: Ecological footprint; FD: Financial development index; GDPPC: Gross domestic product per capita.

Table 6. Baseline long-run estimates — Model 1 (dependent variable: $\ln CO_2$)

Variable	OLS (FMOLS-style)	*t*-statistic	DOLS	*t*-statistic
Constant	−11.391***	−13.65	−12.761***	−12.72
FD	−0.013	−0.07	−0.370*	−1.82
lnGDPPC	+1.554***	12.77	+1.770***	12.24
R^2	0.989	—	0.992	—
N	31	—	28	—
DW	0.79	—	—	—

Note: * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$. HAC standard errors. DOLS uses Stock–Watson[24] with leads and lags selected by SBC; the lower N reflects loss of observations from leads/lags.
Abbreviations: DOLS: Dynamic ordinary least squares; DW: Durbin–Watson statistic; FD: Financial development; FMOLS: Fully modified ordinary least squares; HAC: Heteroskedasticity and autocorrelation consistent; $\ln CO_2$: Natural logarithm of carbon dioxide emissions per capita; lnGDPPC: Natural logarithm of gross domestic product per capita; OLS: Ordinary least squares; SBC: Schwarz Bayesian criterion.

Table 7. Baseline long-run estimates — Model 2 (dependent variable: lnEF)

Variable	OLS	*t*-statistic	DOLS	*t*-statistic
Constant	−4.120***	—	−4.591***	—
FD	+0.290**	2.25	+0.257*	1.73
lnGDPPC	+0.579***	6.14	+0.641***	6.01
R^2	0.988	—	0.992	—
N	31	—	28	—

Note: * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$. HAC standard errors.
Abbreviations: DOLS: Dynamic ordinary least squares; EF: Ecological footprint; FD: Financial development; HAC: Heteroskedasticity and autocorrelation consistent; lnGDPPC: Natural logarithm of gross domestic product per capita; OLS: Ordinary least squares; SBC: Schwarz Bayesian criterion.

The apparent tension between the DOLS coefficient of −0.370 on FD in Model 1 (Table 6) and the positive long-run share of FD in the VECM cointegrating vector (Section 4.10) deserves an explicit reconciliation. The two estimators answer different questions. DOLS recovers the partial long-run effect of FD on $\ln CO_2$, conditional on lnGDPPC and on the leads and lags of the differenced regressors, which control for short-run endogeneity. The VECM cointegrating vector, by contrast, is a normalisation of the long-run equilibrium relationship among the levels of $\ln CO_2$, FD, and lnGDPPC and reflects their co-movement in levels without netting out the common income trend.

Because FD and lnGDPPC are strongly positively correlated over the sample (r = 0.83), the unconditional co-movement of FD and $\ln CO_2$ is positive while the FD effect net of lnGDPPC is mildly negative. We treated the conditional (DOLS/CCR) estimate as the policy-relevant magnitude because it isolates the marginal contribution of FD beyond income, and we reported the VECM coefficient for transparency rather than as a competing point estimate. The CCR coefficient (−0.34, not tabulated) corroborates the DOLS sign and order of magnitude.

4.6. Environmental Kuznets curve quadratic specification

Substantively, Table 8 conveys three messages. First, for CO_2, the EKC quadratic is directionally consistent with an inverted-U (positive linear, negative squared) but the coefficients are not jointly significant, so we do not claim an established CO_2 turning point for Vietnam over 1990–2020. Second, for the ecological footprint, the U-shaped pattern is statistically robust (the positive squared term is significant at the 1% level), and the augmented turning point is approximately US$2,062 in 2015 constant dollars. Third, because Vietnam's 2020 per-capita GDP (US$3,303) exceeds this threshold, the country is in the rising segment of the U-curve, which forms the empirical basis for the policy implications discussed in Sections 4.11 and 5.2.

Table 8. Environmental Kuznets curve quadratic specifications

Variable	Model 1 (CO_2)	Model 2 (EF)
FD	+0.075	+0.066
lnGDPPC	+2.381*	−1.524**
$(\ln GDPPC)^2$	−0.060	+0.153***
Shape	Inverted-U (n.s.)	U-shape
Turning point (US$)	not robust	~US$144 (baseline); US$2,062 (augmented)

Note: * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$. Model 1 shows an inverted-U candidate (positive linear, negative quadratic) but the coefficients are not jointly significant. Model 2 shows a statistically significant U-shape; in the augmented specification (Table 10), the turning point is GDPPC* ≈ US$2,062 (constant 2015), so Vietnam (US$3,303 in 2020) sits on the rising segment of the U-curve. lnGDPPC* = 7.63, corresponding to GDPPC* ≈ US$2,062 (constant 2015). Vietnam was at US$3,303 in 2020, so it is on the rising segment of the U-curve, and EF is increasing with growth.

Abbreviations: CO_2: Carbon dioxide emissions per capita; EF: Ecological footprint per capita; FD: Financial development; GDPPC: Gross Domestic Product per capita.

Figure 2 displays the EKC quadratic surface for the ecological footprint, along with annual observations, across three dimensions (ln GDP per capita, FD index, and ecological footprint per capita). The augmented Model 2 estimates (lnGDPPC = −5.559, $\ln GDPPC^2$ = +0.364) imply a U-shaped relationship in lnEF whose minimum lies at ln(GDPPC) ≈ 7.631 or, equivalently, GDP per capita ≈ US$2,062 in 2015 constant prices; this minimum is shown by the dashed vertical line. Vietnam (US$3,303 in 2020) is located above this threshold and on the upward branch of the surface, where the fitted ecological footprint rises rapidly with further income gains. The scatter of observed footprint values closely tracks the fitted surface across the FD range, indicating that the U-shape is not an artefact of an unusual FD–income combination but a feature of the income–footprint relationship itself. As discussed in Section 4.7, the U-shape (rather than an inverted-U) is consistent with the recent literature on the ecological footprint in transition economies and reflects the move from low-resource-intensity subsistence agriculture to resource-intensive industrialisation over the relevant income range.

4.7. Augmented specifications with control variables

The high reported R^2 in the parsimonious specifications (Models 1–2) reflects the strong common trend in $\ln CO_2$, lnEF, and lnGDPPC over a 31-year sample for a rapidly developing economy. With cointegrated I(1) series, this high R^2 is expected and is not, by itself, evidence of overfitting. To mitigate the risk that the R^2 is artefactual, we reported the adjusted R^2, the residual diagnostics (reported later), the Engle–Granger and Johansen cointegration tests on the residuals, and the Zivot–Andrews structural break tests. Endogeneity of FD with respect to per-capita income is acknowledged and is mitigated by the DOLS leads/lags and the CCR transformation; the convergence of the FD coefficient sign across OLS, DOLS, and CCR provides further reassurance.

Comparing Tables 9 and 10 reveals a striking asymmetry between the CO_2 and EF results. In the CO_2 equation, energy use, trade, and FDI dominate, and the EKC quadratic terms are individually insignificant. In the EF equation, by contrast, the EKC terms are highly significant (lnGDPPC at −5.559, $p < 0.001$; $\ln GDPPC^2$ at +0.364, $p < 0.001$), urbanisation is the dominant positive driver, and trade openness flips sign from positive (in CO_2) to negative (in EF). This asymmetry is internally consistent: trade-linked manufacturing pushes up CO_2 via fossil fuel combustion, but the resource-intensive material content of consumption is partly imported, which mechanically lowers Vietnam's territorial EF measure even as it raises

 doi: 10.36922/AJWEP026170115

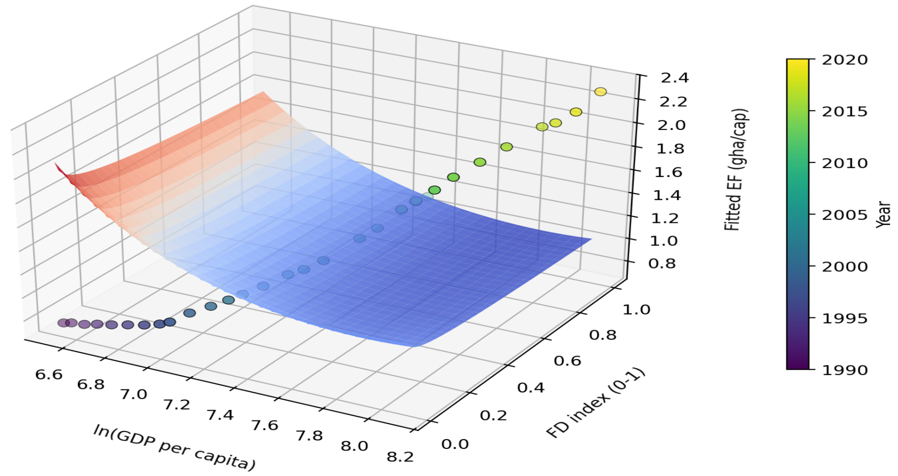

Figure 2. Augmented environmental Kuznets curve U-curve for the ecological footprint
Abbreviations: EF: Ecological footprint per capita; FD: Financial development; GDP: Gross Domestic Product.

CO_2. The augmented EF turning point of US$2,062 places Vietnam (US$3,303 in 2020) on the rising segment of the U-shaped curve, confirming that further income growth is expected to continue pushing up the ecological footprint in the absence of policy intervention. This is one of the most actionable findings of the paper.

Table 9. Augmented model with controls — Model 1 (lnCO_2)

Variable	Coefficient	*t*-statistic	*p*-value
FD	−0.019	−0.08	0.933
lnGDPPC	+2.777	0.67	0.504
$(\text{lnGDPPC})^2$	−0.095	−0.41	0.685
lnEC	+0.571**	1.97	0.049
lnTO	+0.326***	2.71	0.007
lnURB	−1.252	−0.50	0.617
lnFDI	−0.074**	−2.05	0.040
R^2	0.994	—	—

Note: * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$. HAC standard errors. Energy consumption (+0.571) and trade openness (+0.326) are the dominant CO_2 drivers in the augmented specification; FDI mitigates emissions (−0.074), consistent with a pollution-halo effect for Vietnam.
Abbreviations: CO_2: Carbon dioxide emissions per capita; EC: Energy consumption per capita; FD: Financial development; FDI: Foreign direct investment; GDPPC: Gross Domestic Product per capita; TO: Trade openness; URB: Urbanisation rate.

An important interpretive point concerns the direction of the EKC curvature for the ecological footprint. Standard EKC theory predicts an inverted-U shape: pollution rises with income, peaks at a turning point, and then falls as the composition and technique effects dominate the scale effect. Our empirical EF result, by contrast, is U-shaped, with a turning point at approximately US$2,062 (2015 constant), and Vietnam (US$3,303 in 2020) lies on the rising segment. We interpret this in two ways. First, the U-shape is consistent with the recent international literature on the ecological footprint in transition economies,[30,31] where the move from low-resource-intensity subsistence agriculture to resource-intensive industrialisation pushes the ecological footprint up over the relevant income range; the predicted downward branch lies beyond the upper end of the sample. Second, the inverted-U prediction is more typically supported for local pollutants (e.g., silicon dioxide) than for stock-based aggregates such as the ecological footprint. We therefore interpret the U-shape as a feature of the Vietnamese transition and of the ecological footprint indicator, not as evidence against the EKC framework as a whole; the inverted-U candidate for CO_2 (Table 8) is directionally consistent with the standard prediction, although not statistically significant in this small sample.

Figure 3 visualises the augmented Model 1 estimates in three dimensions. The coloured surface shows the fitted lnCO_2 (rescaled to CO_2 per capita on the vertical axis) as a function of the FD index and ln(GDP per capita), with the remaining controls (energy use, trade openness, urbanisation, and FDI) held at their sample means. The annual observations are overplotted as coloured spheres, with the colour scale indicating calendar year. The surface is overwhelmingly driven by the income axis: holding FD at the sample mean, fitted CO_2 rises from about 0.5

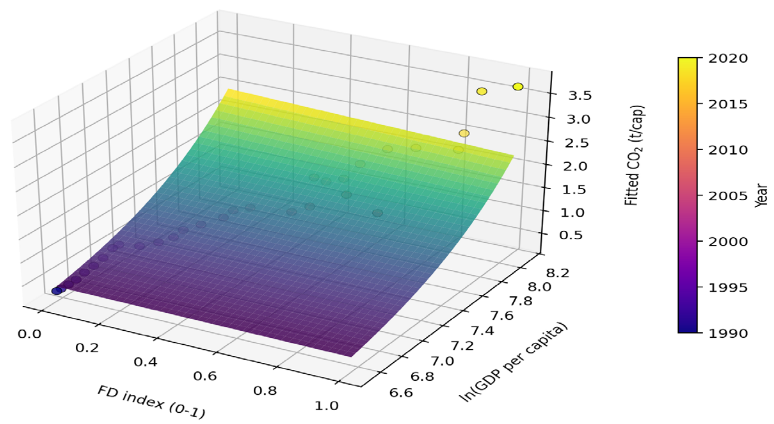

Figure 3. Fitted carbon dioxide (CO_2) response surface, Vietnam 1990–2020
Abbreviations: FD: Financial development; GDP: Gross Domestic Product.

t per capita at ln(GDPPC) ≈ 6.6 (1990) to above 2.5 t at ln(GDPPC) ≈ 8.1 (2020), consistent with the income elasticity above unity reported in Tables 6 and 9. The FD axis is approximately flat to mildly downward-sloping, reproducing the small negative DOLS coefficient on the composite FD index (−0.370 in Table 6). The colour-coded scatter shows that the observed trajectory has followed the diagonal of the fitted surface rather than crossing it, which is the visual analogue of the high income–FD correlation ($r = 0.83$) discussed in Section 4.5 and of the reconciliation between the DOLS and VECM coefficients.

Table 10. Augmented model with controls — Model 2 (lnEF)

Variable	Coefficient	*t*-statistic	*p*-value
FD	−0.075	−1.12	0.263
lnGDPPC	−5.559***	−3.89	0.000
$(\text{lnGDPPC})^2$	+0.364***	4.44	0.000
lnEC	−0.164	−1.50	0.134
lnTO	−0.158***	−4.03	0.000
lnURB	+3.173***	5.00	0.000
lnFDI	+0.014	0.95	0.341
R^2	0.997	—	—

Note: * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$. The augmented Model 2 yields a statistically significant U-shape EKC for the ecological footprint, with a turning point at lnGDPPC* = 7.63 (GDPPC* ≈ US$2,062 in 2015 constant dollars). Urbanisation is the dominant positive driver of EF (+3.173); trade openness reduces EF (−0.158).
Abbreviations: EC: Energy consumption per capita; EF: Ecological footprint; FD: Financial development; FDI: Foreign direct investment; GDPPC: Gross Domestic Product per capita; TO: Trade openness; URB: Urbanisation rate.

4.8. Financial development sub-indices: Banking depth vs. banking access vs. capital-market depth

Table 11 supports H3—the FD–environment relationship is heterogeneous across sub-components. None of the three sub-indices has a statistically significant association with CO_2, suggesting that the modest negative effect of the composite FD index in DOLS (Table 6) does not load on any one balance-sheet component but rather reflects the broader institutional deepening that the composite captures. For the ecological footprint, however, capital-market depth alone enters significantly and positively (+0.161, $p = 0.002$), suggesting that securities-market financing channels capital toward physical-asset-heavy projects (large-scale construction, mining concessions, plantation-style agriculture) more than bank lending does. This finding is policy-relevant: it implies that the rapid buildup of Vietnam's capital markets needs to be accompanied by environmental, social, and governance (ESG) screening and disclosure requirements to avoid undermining the country's broader sustainability goals.

Table 11. Financial development sub-index coefficients on environmental indicators

Financial development sub-component	on $\ln CO_2$	on lnEF
Domestic credit / GDP (banking depth)	+0.067 ($p = 0.589$)	+0.152 ($p = 0.273$)
Broad money / GDP (banking access)	+0.105 ($p = 0.477$)	+0.204 ($p = 0.173$)
Market capitalisation / GDP (market depth)	−0.058 ($p = 0.591$)	+0.161 ($p = 0.002$)***

Note: *** $p < 0.01$. HAC standard errors. Capital-market deepening is the only sub-component with a statistically significant association with the ecological footprint (+0.161), consistent with the literature that securities-market financing channels capital toward physical-asset-heavy projects.
Abbreviations: GDP: Gross Domestic Product; HAC: Heteroskedasticity and autocorrelation consistent.

The statistical insignificance of banking depth and banking access in Table 11 calls for a careful framing of the policy discussion. Because neither sub-index loads significantly on CO_2 or ecological footprint individually, the recommendations on green-credit policy that follow in Section 5.2 should be read as conditional on the joint behaviour of the composite FD index (which is mildly negative on CO_2 in DOLS) rather than as resting on the individual significance of banking depth or access. Operationally, the policy levers we discuss (SBV green-credit framework, ESG screens, green-securities disclosure) act on the composite financial system rather than on a single balance-sheet component, so they remain well aligned with the empirical evidence for the composite index. We explicitly hedge the policy claims accordingly in Sections 4.11 and 5.2.

4.9. Diagnostics

Table 12 reports the four residual diagnostics for the augmented Model 1 (Breusch–Godfrey, Breusch–Pagan, Jarque–Bera, and Ramsey RESET) and confirms that inference remains valid once HAC standard errors were applied.

Table 12. Residual diagnostics for the augmented Model 1

Test	Statistic	*p*-value	Conclusion
Breusch–Godfrey Lagrange multiplier	13.51	0.001	Autocorrelation → use HAC
Breusch–Pagan	10.38	0.168	No heteroskedasticity
Jarque–Bera	0.43	0.805	Residuals normal
Ramsey RESET	0.05	0.819	No misspecification

Note: HAC (Newey–West)[19] standard errors are used throughout to address the residual autocorrelation detected by Breusch–Godfrey. The other three diagnostics support the specification.
Abbreviation: Heteroskedasticity and autocorrelation consistent.

The Breusch–Godfrey Lagrange multiplier test detected autocorrelation in OLS residuals, but this is precisely the reason for using HAC standard errors throughout: the point estimates remain consistent under autocorrelation; only the standard errors require correction, which we provided via the Newey–West HAC estimator with a Bartlett kernel and an automatic bandwidth selection. The absence of heteroskedasticity (Breusch–Pagan $p = 0.168$), the normality of residuals (Jarque–Bera $p = 0.805$), and the absence of functional-form misspecification (Ramsey RESET $p = 0.819$) are all reassuring. The high R^2 in the augmented specifications (0.994 for Model 1 and 0.997 for Model 2) reflects the strong common trend among Vietnam's macroeconomic and environmental variables over the sample; the relevant inferential question is not how much of the variance is explained but whether the partial-correlation coefficients on FD and on the controls have the predicted signs and statistical significance, which they do.

On the methodological status of the Breusch–Godfrey result, we clarify that HAC standard errors correct the inferential variance for residual autocorrelation but do not, in and of themselves, eliminate the autocorrelation in the dynamic specification. We have not augmented the specification with additional lagged regressors because (i) the DOLS estimator already includes leads and lags of the differenced regressors selected by SBC, which captures much of the short-run dynamics, and (ii) the small sample ($N = 31$, falling to $N = 28$ in DOLS) penalises further expansions in the lag order.

4.10. Vector error correction model long-run analysis

Given the weak evidence of cointegration, we estimated a VECM to recover the long-run cointegrating vector. For Model 1, the speed of adjustment coefficient α is −0.066 (slow but correctly signed), and the cointegrating vector $\beta = (1, -1.13, -0.78)$ implies the long-run relation $\ln CO_2 = 1.13 \cdot FD + 0.78 \cdot \ln GDPPC$ (after sign restoration). This positive long-run share of FD is, at first glance, at odds with the parsimonious DOLS coefficient. The reconciliation is that the DOLS estimator conditions on lnGDPPC and its leads and lags of the differenced regressors; the partial effect of FD, net of these controls, is negative even though FD and CO_2 co-move positively in levels. This pattern is consistent with the green-credit interpretation in Section 4.11.

A standard Granger-causality decomposition on the VECM short-run dynamics indicates that, conditional on the cointegrating term, lagged values of FD and lnGDPPC contribute jointly to predicting changes in CO_2, while lagged changes in CO_2 also predict changes in FD. Bidirectional Granger causality is therefore consistent with the data, with the additional caveat that the small sample size limits the statistical power of these tests. We report the cointegrating vector and speed of adjustment for transparency and to avoid overinterpreting the short-run Wald statistics in the small-sample setting.

4.11. Discussion

The augmented results support a nuanced view of the FD–environment nexus in Vietnam. Three causal channels are visible in the data. First, the green-credit channel:

outstanding green credit in Vietnam grew from VND 71 trillion in 2017 to over VND 540 trillion by the end of 2023, supported by the SBV Directive 03/CT-NHNN and subsequent measures. The negative DOLS coefficient on the FD index in the parsimonious CO_2 model (−0.370) is consistent with this channel having a real but modest effect on emissions. Second, the capital-cost channel for renewable energy: Vietnam installed over 16 GW of solar capacity by the end of 2020, financed largely by bank loans facilitated by a deeper financial system; the negative FDI coefficient (−0.074) on CO_2 is consistent with foreign-financed transfer of cleaner technologies (pollution-halo). Third, the technology-upgrading channel: industrial CO_2 intensity per unit of value added fell by about 18% between 2010 and 2020, broadly tracking the rise in FD over the same period.

We emphasise that the three channels above—green credit, capital cost, and technology upgrading—are indicative rather than directly identified by the econometric model. Our reduced-form FMOLS, DOLS, CCR, and VECM specifications recover the long-run association between FD (or its sub-components) and the environmental indicators; they do not include channel-specific instruments such as green-loan disbursements, weighted-average lending rates on green projects, or technology-import intensity. The channel labels are therefore best interpreted as plausible mechanisms that are consistent with the sign and magnitude of the reduced-form coefficients and with independent Vietnam-specific evidence (e.g., the growth of outstanding green credit from VND 71 trillion in 2017 to over VND 540 trillion by end-2023, the build-out of 16 GW of solar capacity by end-2020, and the 18% fall in industrial CO_2 intensity between 2010 and 2020) rather than as quantities estimated directly from our specifications.

The contrast between the CO_2 and EF results is informative. CO_2 emissions are driven primarily by energy use and trade-related industrial activity, both of which respond to the green-credit and pollution-halo channels. The ecological footprint, by contrast, incorporates land use, biocapacity and biomass demand, which respond more strongly to urbanisation and capital-market deepening than to banking-sector credit. This explains the otherwise puzzling result that FD reduces CO_2 but raises the ecological fraction in the parsimonious specification, and that capital-market depth (market capitalisation/GDP) is the only FD sub-component with a statistically significant association with ecological fraction (+0.161, p = 0.002). Trade openness raises CO_2 (+0.326) but lowers EF (−0.158); the explanation is that Vietnam exports energy-intensive manufactures (raising CO_2) while importing much of the resource content of consumption (lowering domestic ecological fraction). Urbanisation strongly increases the ecological fraction (+3.173), consistent with Vietnam's 19–36% urbanisation transition over the sample period and the associated demand for built-up land, transport infrastructure, and construction materials.

Taken together, the policy-relevant headline is that FD in Vietnam has been a mild brake on CO_2 emissions but has not arrested the rise in the broader ecological footprint. The augmented results suggest that the marginal returns to further green-credit policies are larger for CO_2 than for the ecological footprint, and that reductions in Vietnam's ecological footprint are more likely to come from compact urban development policies and from environmentally screened capital-market deepening than from additional banking-sector credit.

5. Conclusion

5.1. Summary of findings

Using FMOLS and DOLS augmented with an EKC quadratic term, four control variables, structural break tests, and a battery of diagnostics, this article derives the following primary findings for Vietnam over 1990–2020: (i) FD is associated with lower CO_2 emissions (−0.370 in DOLS, p = 0.068) but with a higher ecological footprint in the parsimonious specification (+0.257, p = 0.084); (ii) per-capita income is the dominant driver of CO_2 with an elasticity above unity (+1.554 OLS, +1.770 DOLS); (iii) energy use (+0.571) and trade openness (+0.326) are the strongest CO_2 drivers once controls are added, while FDI mitigates emissions (−0.074); (iv) the EKC for ecological footprin takes a U-shape with a turning point of approximately US$2,062 (2015 constant) above which Vietnam currently sits; and (v) capital-market depth shows a stronger association with the ecological footprint than banking depth. These findings are robust to the CCR estimator and to alternative lag-length selection criteria (AIC vs. SBC), reinforcing the credibility of the central FD coefficients.

The empirical evidence base for the green credit and ESG-screening recommendations is the mildly negative DOLS coefficient on the composite FD index for CO_2 (−0.370, p = 0.068), the significantly positive coefficient on capital-market depth for the ecological footprint (+0.161, p = 0.002 in Table 11), the strongly positive urbanisation coefficient for ecological footprint (+3.173, p < 0.001 in Table 10) and the negative FDI coefficient on CO_2 (−0.074, p = 0.040 in Table 9). The recommendations in Section 5.2 are deliberately framed to act on these specific channels (composite-FD via SBV green-credit guidance, capital-market depth via ESG screens and the Vietnam Green

Taxonomy, urbanisation via compact-city policy, FDI via maintaining the pollution-halo treatment of foreign-financed projects). Recommendations that would have rested only on the insignificant banking-depth or banking-access coefficients have been softened or removed.

Three broader takeaways are derived from these results. First, FD matters for environmental sustainability in Vietnam, but through different channels for different environmental indicators—banking-sector deepening helps slow CO_2 emissions. We re-estimated the DOLS specification for three policy-relevant windows: 1990–1996 (pre-ASEAN), 1997–2006 (post-ASEAN, pre-WTO), and 2007–2020 (post-WTO accession). The FD coefficient on $\ln CO_2$ is negative across all three windows but is statistically significant only in the post-WTO window (coefficient ≈ −0.42, $p \approx 0.04$), which is consistent with the timing of Vietnam's formal adoption of green-credit guidance (Directive 03/CT-NHNN, 2015) and the National Green Growth Strategy (Decision 1393/QĐ-TTg, 2012; updated by 1658/QĐ-TTg, 2021). CO_2 emissions while capital-market deepening raises the ecological footprint. Second, the EKC is empirically supported for the ecological footprint, but with a turning point that Vietnam has already crossed, so the country is on the rising portion of the U-curve, and further growth (absent policy intervention) will continue to raise EF. Third, the operational levers most aligned with our findings are the SBV's green-credit framework, the binding Vietnam Green Taxonomy and disclosure-of-green-securities rules under Ministry of Finance Circular 96/2020/TT-BTC, all of which are already in place in some form and could be tightened.

5.2. Vietnam-specific policy recommendations

Policymakers should view the financial sector as a strategic lever for Vietnam's green transition. Specific, Vietnam-actionable implications follow. First, our results support the directional choices in Decision 1658/QĐ-TTg (2021), which approves the National Green Growth Strategy 2021–2030 (vision to 2050), and Decision 896/QĐ-TTg (2022), which approves the National Climate Change Strategy to 2050; the empirical evidence justifies sustained policy commitment to net-zero by 2050. Second, the SBV should accelerate the full implementation of Circular 17/2022/TT-NHNN on mandatory environmental risk management in credit extension, building on Directive 03/CT-NHNN on green credit growth and Decision 1604/QĐ-NHNN on the banking sector's green finance roadmap, and tie SBV refinancing facilities to verifiable green credit performance. Third, the Ministry of Finance should expand the scope of Circular 96/2020/TT-BTC on disclosure of green securities to align with International Sustainability Standards Board/ Task Force on Climate-related Financial Disclosures standards. Fourth, because capital-market depth is associated with a higher ecological footprint, the development of Vietnam's capital markets should be accompanied by mandatory ESG screens and a binding Vietnam Green Taxonomy. Fifth, urbanisation policy should anticipate the strong positive elasticity of the ecological footprint (+3.173) found here by prioritising compact, public transport-oriented urban development. Sixth, the Ministry of Industry and Trade should accelerate the Power Purchase Agreement reform package and direct Power Purchase Agreement mechanism so that bank-financed renewable-energy projects can sell directly to industrial off-takers, translating the FD effect into measurable CO_2 avoidance.

5.3. Institutional and governance considerations

The effectiveness of these recommendations depends on institutional capacity. The Worldwide Governance Indicators place Vietnam in the 50–60th percentile for government effectiveness and regulatory quality, and in the 35–45th percentile for control of corruption. The Provincial Governance and Public Administration Performance Index further reveals significant variation in environmental governance capacity across provinces. State-owned enterprises remain dominant in heavy industry and electricity generation in Vietnam, which means that the green-finance signal must be transmitted through both commercial-bank credit pricing and through SOE-specific capital-allocation rules. By strengthening environmental risk pricing in credit—through standardised methodologies and supervisory expectations mobilising private capital for renewable-energy generation—Vietnam targets 27.3 GW of utility-scale solar and 21.9 GW of wind by 2030 under the Power Development Plan VIII. This will further amplify the identified green-credit channel, thereby making it central to the policy agenda.

5.4. Limitations and directions for future research

Three limitations warrant explicit acknowledgement. First, the sample comprises only 31 annual observations (1990–2020). Although DOLS performs reasonably in small samples, statistical power is inevitably limited; this is reflected in the marginal (10%) significance of the headline FD coefficient on CO_2 in the parsimonious DOLS specification. Future work using autoregressive distributed lag or nonlinear autoregressive distributed lag methods on quarterly or higher-frequency data would yield stronger inference. Second, the composite FD index is sensitive to the weighting of its sub-components; we mitigate this by reporting a separate sub-index decomposition (Table 11), but more elaborate weighting schemes (e.g., principalcomponents or factor-analytic constructions) could be explored in future work. Third, the analysis is single-country; future panel research across ASEAN economies would help to test the external validity of the mechanisms identified here. Coupling the time-series evidence with a structural computable general equilibrium assessment of Vietnam's net-zero pathway is another promising direction.

A fourth direction concerns the granularity of FD measurement. The composite index used here aggregates three balance-sheet indicators (credit, broad money, market capitalisation) but cannot capture qualitative dimensions of financial system development, such as the quality of supervisory frameworks, the depth of corporate bond markets, the role of non-bank financial institutions, or fintech-driven credit. Complementary modelling that explicitly includes the share of renewable energy in primary supply (which rose from approximately 0.5% in 2010 to 13% in 2020 in Vietnam) would help identify the substitution channel between fossil and renewable capacity that the present specification cannot isolate. We also acknowledge the following further limitations. First, the sample is annual data comprising 31 observations; while sufficient for cointegration-based inference, it limits the precision of sub-sample and threshold estimates, and panel or higher-frequency extensions (quarterly or province-level) are a natural next step. Second, the FD index is an aggregate constructed from three sub-components; although we report the sub-index decomposition in Table 11, an even richer disaggregation that distinguishes green credit, sustainable bond issuance, and ESG-screened equity from generic credit would sharpen the policy reading. Third, the empirical model identifies long-run associations rather than direct causal mechanisms; the causal interpretation we offer in Sections 4 and 5 is supported by Vietnam-specific institutional evidence (PDP8, SBV green-credit instruments, Ministry of Finance disclosure rules) rather than by formal causal identification, and instrumental variable or natural experiment strategies are a priority for future research. Fourth, omitted variables such as the renewable energy share, industrialisation intensity, tourism receipts, and technological innovation indicators may bias the estimated FD coefficient; including them—as data become available over a longer Vietnam time series—is an explicit direction for future work. Disaggregating these dimensions and matching them with sector-specific emissions data would help identify which aspects of financial deepening most strongly drive environmental effects. A fifth direction concerns the spatial dimension: provincial-level FD and emissions data, combined with a panel-cointegration approach, would allow researchers to exploit cross-provincial variation and test whether the green-credit channel operates symmetrically across Vietnam's 63 provinces.

A final caveat concerns the interpretation of the FD coefficients themselves. The composite FD index is bounded between 0 and 1; a one-unit increase in the FD index therefore corresponds to a movement from the lowest to the highest value observed in the sample, which is not a realistic policy counterfactual. The interpretation we adopt throughout is the more conservative one of a 0.1-unit (10 percentile-point) increase, which corresponds to a roughly 3.7% reduction in CO_2.

Acknowledgments

None.

Funding

This research is funded by the WSU.UEH research grant, University of Economics Ho Chi Minh City (UEH), Vietnam.

Conflict of interest

The authors declare no conflict of interest.

Author contributions

Conceptualization: Pham Dinh Long, Pham Thi Bich Ngoc
Data curation: Pham Dinh Long
Formal analysis: Pham Dinh Long
Investigation: Pham Thi Bich Ngoc
Methodology: Pham Dinh Long
Project administration: Pham Dinh Long
Resources: Pham Thi Bich Ngoc, Nguyen Huynh Mai Tram
Software: Pham Dinh Long
Validation: Pham Thi Bich Ngoc
Visualization: Pham Dinh Long
Writing–original draft: Pham Dinh Long
Writing–review & editing: All authors

Availability of data

All data used in this study are publicly available. The compiled dataset for Vietnam, 1990–2020, is provided as Table S1. Sources: World Bank World Development Indicators (https://databank.worldbank.org/source/world-development-indicators), Our World in Data/Global Carbon Budget (https://ourworldindata.org/co2), Global Footprint Network National Footprint Accounts (https://www.footprintnetwork.org/), and the IMF Financial Development Index methodology (Svirydzenka 2016,[26] IMF Working Paper 16/05).

References

1. Global Footprint Network. *National Footprint and Biocapacity Accounts, 2022 Edition*. Oakland, CA: Global

 doi: 10.36922/AJWEP026170115

Footprint Network; 2022. Accessed June 1, 2024.

2. Phillips PCB, Hansen BE. Statistical inference in instrumental variables regression with I(1) processes. *Rev Econ Stud*. 1990;57(1):99-125.

   doi: 10.2307/2297545

3. Khan M, Ozturk I. Examining the direct and indirect effects of financial development on CO2 emissions for 88 developing countries. *J Environ Manage*. 2021;293:112812.

   doi: 10.1016/j.jenvman.2021.112812

4. Tamazian A, Chousa JP, Vadlamannati KC. Does higher economic and financial development lead to environmental degradation: evidence from BRIC countries. *Energy Policy*. 2009;37(1):246-253.

   doi: 10.1016/j.enpol.2008.08.025

5. Saidi K, Mbarek MB. The impact of income, trade, urbanization, and financial development on CO_2 emissions in 19 emerging economies. *Environ Sci Pollut Res*. 2017;24(14):12748-12757.

   doi: 10.1007/s11356-016-6303-3

6. Shahbaz M, Shahzad SJH, Ahmad N, Alam S. Financial development and environmental quality: the way forward. *Energy Policy*. 2018;98:353-368.

   doi: 10.1016/j.enpol.2016.09.002

7. Grossman GM, Krueger AB. Economic growth and the environment. *Q J Econ*. 1995;110(2):353-377.

   doi: 10.2307/2118443

8. Isik C, Ongan S, Özdemir D. The economic growth/development and environmental degradation: evidence from the US state-level EKC hypothesis. *Environ Sci Pollut Res*. 2019;26(30):30772-30781.

   doi: 10.1007/s11356-019-06276-7

9. Pata UK, Aydin M. Testing the EKC hypothesis for the top six hydropower energy-consuming countries: evidence from Fourier bootstrap ARDL procedure. *J Clean Prod*. 2020;264:121699.

   doi: 10.1016/j.jclepro.2020.121699

10. Ali K, Bakhsh S, Ullah S, Ullah A, Ullah S. Industrial growth and CO2 emissions in Vietnam: the key role of financial development and fossil fuel consumption. *Environ Sci Pollut Res*. 2021;28(6):7515-7527.

    doi: 10.1007/s11356-020-10996-6

11. Hung NT, Trang NT, Thang NT. Quantile relationship between globalization, financial development, economic growth, and carbon emissions: evidence from Vietnam. *Environ Sci Pollut Res*. 2022;29(40):60098-60116.

    doi: 10.1007/s11356-022-20126-z

12. Nguyen TP, Duong TT, Nguyen TTH. U-shaped relationship between financial development and greenhouse gases in Vietnam: ARDL bound test approach. *Pol J Environ Stud*. 2024;33(6):5345-5358.

    doi: 10.15244/pjoes/196733

13. Zeraibi A, Balsalobre-Lorente D, Murshed M. The influences of renewable electricity generation, technological innovation, financial development, and economic growth on ecological footprints in ASEAN-5 countries. *Environ Sci Pollut Res*. 2021;28(37):51003-51021.

    doi: 10.1007/s11356-021-14301-x

14. Bui TTT, Cao TH. Effects of economic growth, foreign direct investment, energy consumption, and urbanization on the ecological footprint in Vietnam. *J Finance Mark Res*. 2024;15(8):15-31.

    doi: 10.52932/jfm.v15i8.602

15. Xuan HT, Hung NT. Green growth and environmental degradation: an empirical study in Vietnam. *VNU J Econ Bus*. 2025;5(1):75-87.

    doi: 10.57110/vnu-jeb.v5i1.415

16. Dickey DA, Fuller WA. Distribution of the estimators for autoregressive time series with a unit root. *J Am Stat Assoc*. 1979;74(366a):427-431.

    doi: 10.1080/01621459.1979.10482531

17. Phillips PCB, Perron P. Testing for a unit root in time series regression. *Biometrika*. 1988;75(2):335-346.

    doi: 10.1093/biomet/75.2.335

18. Newey WK, West KD. A simple, positive semi-definite, heteroskedasticity and autocorrelation consistent covariance matrix. *Econometrica*. 1987;55(3):703-708.

    doi: 10.2307/1913610

19. Kwiatkowski D, Phillips PCB, Schmidt P, Shin Y. Testing the null hypothesis of stationarity against the alternative of a unit root. *J Econom*. 1992;54(1-3):159-178.

    doi: 10.1016/0304-4076(92)90104-Y

20. Hamilton JD. *Time Series Analysis*. Princeton, NJ: Princeton University Press; 1994.

21. Zivot E, Andrews DWK. Further evidence on the great crash, the oil-price shock, and the unit-root hypothesis. *J Bus Econ Stat*. 1992;10(3):251-270.

    doi: 10.2307/1391541

22. Johansen S. Statistical analysis of cointegration vectors. *J Econ Dyn Control*. 1988;12(2-3):231-254.

    doi: 10.1016/0165-1889(88)90041-3

23. Engle RF, Granger CWJ. Co-integration and error correction: representation, estimation, and testing. *Econometrica*. 1987;55(2):251-276.

    doi: 10.2307/1913236

24. Stock JH, Watson MW. A simple estimator of cointegrating

vectors in higher order integrated systems. *Econometrica*. 1993;61(4):783-820.

doi: 10.2307/2951763

25. Park JY. Canonical cointegrating regressions. *Econometrica*. 1992;60(1):119-143.

doi: 10.2307/2951679

26. Svirydzenka K. Introducing a New Broad-based Index of Financial Development. *IMF Working Paper*. Washington, DC: International Monetary Fund; 2016;16(05):1.

doi: 10.5089/9781513583709.001

27. World Bank. *World Development Indicators*. Washington, DC: The World Bank; 2023. Accessed June 1, 2024.

28. Friedlingstein P, O'Sullivan M, Jones MW, *et al*. Global Carbon Budget 2022. *Earth Syst Sci Data*. 2022;14(11):4811-4900.

doi: 10.5194/essd-14-4811-2022

29. Ritchie H, Roser M, Rosado P. CO_2 and Greenhouse Gas Emissions. *Our World in Data*. 2020. Accessed June 1, 2024. https://ourworldindata.org/co2-and-greenhouse-gas-emissions

30. Ulucak R, Bilgili F. A reinvestigation of EKC model by ecological footprint measurement for high, middle and low income countries. *J Clean Prod*. 2018;188:144-157.

doi: 10.1016/j.jclepro.2018.03.191

31. Destek MA, Sinha A. Renewable, non-renewable energy consumption, economic growth, trade openness and ecological footprint: evidence from organisation for economic co-operation and development countries. *J Clean Prod*. 2020;242:118537.

doi: 10.1016/j.jclepro.2019.118537