“The nexus of economic growth, foreign direct investment, and environmental sustainability: An empirical evidence”

AUTHORS	Suyanto Suyanto Michael Wijaya

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Suyanto Suyanto (Indonesia), **Michael Wijaya** (Indonesia)

THE NEXUS OF ECONOMIC GROWTH, FOREIGN DIRECT INVESTMENT, AND ENVIRONMENTAL SUSTAINABILITY: AN EMPIRICAL EVIDENCE

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Suyanto Suyanto, Dr., Professor, Department of Economics, Faculty of Business and Economics, University of Surabaya, Indonesia. (Corresponding author)

Michael Wijaya, Assistant Researcher, Department of Economics, Faculty of Business and Economics, University of Surabaya, Indonesia.

Abstract

Economic growth and foreign direct investment constitute critical determinants of environmental sustainability. This study empirically examines the nexus between these factors and environmental degradation, proxied by the ecological footprint and carbon emissions, while controlling for urbanization and natural resource depletion. Leveraging the strictly complete panel dataset from 17 selected Asian economies spanning 1990 to 2023, the analytical framework incorporates a comprehensive suite of diagnostic tests, including assessments of multicollinearity, cross-sectional dependence, stationarity, cointegration, and model specification. Diagnostic results confirm the absence of multicollinearity, establish stationarity at first differences, and validate long-run cointegration for both environmental models. Empirical evidence delineates five key findings. First, economic growth exhibits a positive and significant impact on both ecological footprint and carbon emissions, whereas its squared term exerts a negative and significant effect, corroborating the Environmental Kuznets Curve. Second, foreign direct investment increases the ecological footprint significantly, supporting the Pollution Haven Hypothesis. Conversely, foreign direct investment reduces carbon emissions, suggesting the presence of the Pollution Halo Hypothesis. Next, urbanization significantly amplifies the ecological footprint but mitigates carbon emissions. Finally, natural resource depletion significantly reduces the ecological footprint while intensifying carbon emissions. Collectively, these results underscore the complex roles of economic growth and foreign direct investment in environmental sustainability and affirm the concurrent applicability of the Environmental Kuznets Curve, Pollution Haven, and Pollution Halo theoretical frameworks within the Asian context.

Keywords environment, growth, carbon, ecology, investment, resource

JEL Classification F64, O13, O44, Q01, Q56

INTRODUCTION

In today's globalized economy, many multinational enterprises engage in foreign direct investment, with these entities predominantly being large enterprises (Mai, 2020; Wang & Zhou, 2019). Several studies suggest that foreign investment not only positively influences a nation's economic growth but also boosts production and job creation in the host country (Li & Liu, 2005; Liang et al., 2021; Lakemann et al., 2025; Pham & Nguyen-Huu, 2025). Despite the numerous benefits that foreign investment offers to host countries, it can also negatively impact environmental sustainability (Tsoy & Heshmati, 2023; Ly-My et al., 2023). Some multinational enterprises enter host countries due to less stringent environmental regulations, which lead to reduced production costs (Fang, 2024; Gao, 2023). Consequently, environmental degradation is likely to occur in the host country (Sun et al., 2022; Wang et al., 2020).

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The adverse effects of foreign direct investment that elevate carbon emissions can be mitigated through the adoption of low-carbon technologies or a transition toward service sectors (Zhu et al., 2016). As the influx of foreign direct investment into a country increases, so does carbon dioxide pollution, a concern particularly pertinent to companies employing non-environmentally friendly equipment, as evidenced by the Pollution Haven Hypothesis (Naqvi et al., 2023). Moreover, it is posited that foreign investment implements superior and more environmentally sustainable management practices, a concept encapsulated in the Pollution Halo Hypothesis. Consequently, the ecological footprint remains largely unaffected by such foreign direct investment (Zarsky, 1999). Environmental sustainability may, in turn, enhance the per capita income of host countries, as suggested by the Environmental Kuznets framework (Ahmad et al., 2021).

1. LITERATURE REVIEW AND HYPOTHESES

The interplay among economic expansion, foreign direct investment (FDI), and environmental quality constitutes a cornerstone of contemporary environmental economics. As developing and emerging economies pursue industrialization, the inherent tension between growth trajectories and ecological preservation remains a pressing policy imperative. Scholarly discourse has predominantly framed this relationship through three theoretical paradigms: the Environmental Kuznets Curve, the Pollution Haven Hypothesis, and the Pollution Halo Hypothesis.

Seminal contributions by Grossman and Krueger (1991, 1995) posited the Environmental Kuznets hypothesis, characterizing the growth–environment nexus as an inverted U-shaped relationship wherein environmental degradation initially escalates with income but eventually attenuates beyond a critical developmental threshold. Foundational syntheses by Dinda (2004) and Stern (2004) formalized this theoretical architecture. Subsequent empirical validations across diverse regional contexts have largely corroborated the Environmental Kuznets framework, albeit with heterogeneous income turning points. For instance, Pao and Tsai (2010, 2011) substantiated the hypothesis for BRICS economies using CO_2 emissions, while Halicioglu (2009) and Iwata et al. (2010) confirmed its applicability to Turkey and Japan, respectively. Within the Asian domain, Sinha and Shahbaz (2018) identified Environmental Kuznets compliance in India (1971–2015) via autoregressive distributed lag cointegration, and Dong et al. (2018) and Zhang et al. (2022) provided analogous evidence across 14 Asia-Pacific economies and China. Recent panel studies by Onofrei et al. (2022) for European Union member states, Ahmad et al. (2021) using gross domestic product and ecological footprint across seven nations, and Wang et al. (2022) and Balsalobre-Lorente et al. (2022) for middle-income countries further reinforce the inverted U-shaped paradigm.

Notwithstanding these findings, contemporary scholarship increasingly critiques the exclusive reliance on CO_2 as a singular environmental proxy. Ahmed et al. (2020), Destek et al. (2018), Murshed et al. (2022), Naqvi et al. (2023), and Ozturk et al. (2016) contend that CO_2 inadequately captures the multidimensional nature of anthropogenic environmental pressure. Panel analyses across emerging markets reveal that while the Environmental Kuznets Curve often holds for carbon emissions, its validity for the ecological footprint remains more nuanced. Studies by Dogan and Turkekul (2016), Feriansyah et al. (2022), and Ozcan (2013) within Middle Eastern and Asian contexts underscore that ecological sustainability typically materializes only at advanced stages of economic maturation. Conversely, Saboori et al. (2012) and Saboori and Sulaiman (2013) caution that several Southeast Asian economies exhibit no discernible Environmental Kuznets turning point, implying that unfettered growth, absent robust environmental governance, may fail to yield sustainability dividends.

The environmental implications of FDI remain theoretically and empirically contested, primarily bifurcated between the Pollution Haven Hypothesis and the Pollution Halo Hypothesis. The Pollution Haven Hypothesis, originally articulated by Copeland and Taylor (1994) and later refined by Javorcik and Wei (2003), posits that multinational enterprises strategically relocate emission-intensive operations to jurisdictions with lax environmental standards. Empirical support for the Polution Haven Hypothesis in Asian and Middle Eastern economies is documented by Al-Mulali (2011), Al-Mulali and Tang (2013), and Solarin and Shahbaz (2013), who observe that FDI inflows frequently exacerbate carbon emissions. Dietzenbacher and Mukhopadhyay (2007) corroborate this dynamic in India, while Benzerrouk et al. (2021) demonstrate that developed economies frequently outsource polluting industrial processes to developing counterparts, thereby reinforcing Pollution Haven Hypothesis mechanisms. In contrast, the Pollution Halo Hypothesis contends that FDI facilitates environmental amelioration through the transfer of advanced technologies, superior managerial practices, and stringent corporate environmental standards. Mrabet and Alsamara (2017) and Charfeddine (2017) identify halo effects in Qatar and North Africa, where FDI correlates with diminished emission intensities. Within Asia, Zafar et al. (2019) and Sinha et al. (2017) demonstrate that FDI mitigates ecological degradation when coupled with robust institutional frameworks, a finding echoed by Danish et al. (2017), who emphasize the mediating role of host-country absorptive capacity. Recent investigations by Mahmood et al. (2020) and Wang et al. (2016) suggest a dualistic FDI impact: infrastructure-driven expansion may elevate the ecological footprint, whereas technological spillovers concurrently suppress carbon intensity, a duality that aligns with the present study's empirical orientation.

Urbanization operates as a critical determinant in environmental modeling, exerting divergent effects contingent upon developmental stage and spatial planning. Hossain (2011, 2012) and Islam et al. (2013) establish that rapid, unregulated urbanization in developing Asia typically escalates energy demand and CO_2 emissions. Conversely, Uddin (2018) and Rahman (2017) argue that agglomeration economies and efficient urban infrastructure can yield scale efficiencies, thereby reducing per capita emissions. This dichotomy is reinforced by Arif et al. (2023) and Chen et al. (2022), who document that while urbanization initially drives ecological footprint expansion, it may subsequently catalyze low-carbon transitions through enhanced service-sector integration and technological diffusion.

Natural resource depletion introduces additional complexity to the growth–environment paradigm. Apergis and Payne (2009, 2010) highlight the "resource curse" mechanism, wherein resource abundance correlates with elevated pollution levels due to extractive industrialization and weakened institutional oversight. Conversely, Gokmenoglu et al. (2020) and Katircioglu et al. (2018) posit that resource rents can finance environmental mitigation initiatives and green infrastructure. Acaravci and Ozturk (2010) and Ozturk and Acaravci (2013) further emphasize that the ecological footprint and carbon emissions respond asymmetrically to resource extraction, warranting disaggregated analytical treatment.

Methodologically, the literature has progressively transitioned from univariate time-series models to sophisticated panel econometric frameworks that explicitly address cross-sectional dependence, slope heterogeneity, and structural breaks. Lean and Smyth (2010) and Nasir et al. (2019) employ panel cointegration techniques for Southeast Asian and broader Asian samples, underscoring the necessity of rigorous unit root and diagnostic testing. Baek (2015) and Lau et al. (2014) utilize Granger causality frameworks, frequently identifying bidirectional feedback loops between economic growth and environmental degradation. Region-specific analyses by Shakouri et al. (2017) and Tang and Tan (2015) highlight pronounced heterogeneity across East, South, and Southeast Asia, cautioning against pooled estimations that neglect structural instability or model misspecification. Contemporary studies by Xu et al. (2019), Lin and Liu (2018), and Du et al. (2019) routinely incorporate variance inflation factor diagnostics to mitigate multicollinearity bias, while He et al. (2022), Huang et al. (2025), and Luo et al. (2023) stress the imperative of controlling for cross-sectional dependence driven by regional trade integration and financial linkages.

Despite extensive scholarly engagement with the growth–environment nexus, critical gaps persist regarding the simultaneous examination of ecological footprint and carbon emissions under the conjoint influence of FDI, urbanization, and resource

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depletion in Asia. Recent calls by Hussain et al. (2023), Song et al. (2021), and Wu et al. (2025) advocate for integrated econometric specifications that treat urbanization and resource depletion as endogenous controls rather than exogenous additives.

The present study addresses these lacunae by deploying a robust panel econometric framework across a selected balanced panel of 17 Asian economies, concurrently testing the Environmental Kuznets Curve, Pollution Haven, and Pollution Halo hypotheses. By rigorously evaluating the inverted U-shaped growth trajectory and the dual environmental externalities of FDI, this paper extends the foundational discourse initiated by Grossman and Krueger (1991) and advanced by contemporary scholars (for example, Hussain et al., 2023). Accordingly, the following hypotheses are formulated:

H1: *Gross Domestic Product has an inverted U-shape relationship with ecological footprints.*

H2: *The squared Gross Domestic Product has a negative impact on ecological footprints.*

H3: *Foreign direct investment generates a positive effect on ecological footprints.*

H4: *Urbanization has a positive effect on ecological footprints.*

H5: *Natural resource depletion provides a positive impact on ecological footprints.*

H6: *Gross Domestic Product posits an inverted U-shape relationship with carbon emission.*

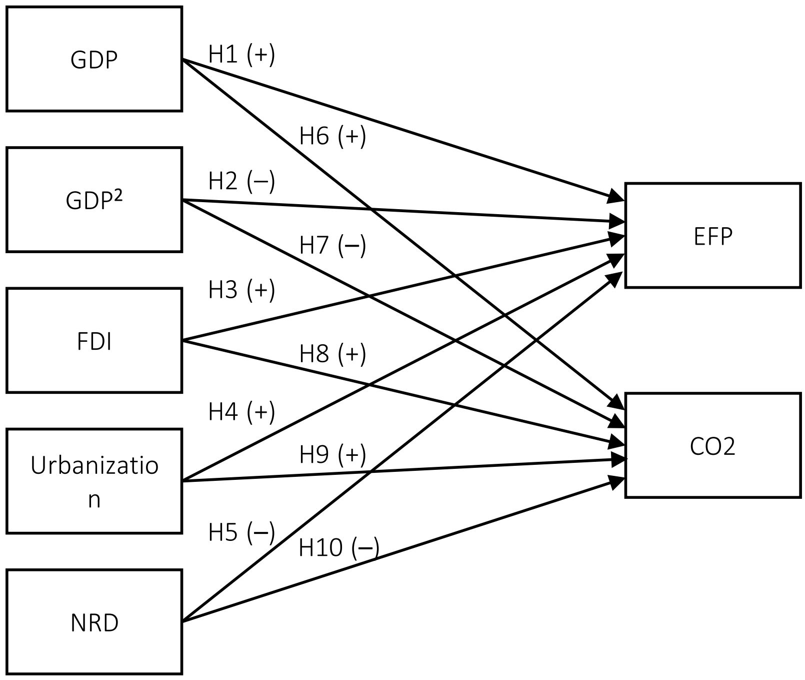
H7: *The squared Gross Domestic Product has a negative impact on carbon emission.*

H8: *Urbanization generates a positive impact on carbon emission.*

H9: *Foreign direct investment has a positive relationship with carbon emission.*

H10: *Natural resource depletion provides a positive effect on carbon emission.*

The empirical framework for this current study is presented in Figure 1.



Note: EFP = ecological footprint; CO_2 = CO_2 emissions; GDP = gross domestic product; FDI = foreign direct investment; URB = urbanization; NRD = natural resource depletion.

Figure 1. Empirical framework

2. METHODS

This study empirically evaluates the applicability of the Environmental Kuznets Curve, the Pollution Haven Hypothesis, and the Pollution Halo Hypothesis within a panel of selected Asian economies. Recognizing the multidimensional nature of environmental degradation, the analysis employs two complementary proxies: the ecological footprint (EFP) and carbon dioxide (CO_2) emissions. The core explanatory variables comprise economic growth, measured by real gross domestic product (GDP) and its squared term (GDP^2), alongside foreign direct investment (FDI) inflows. Urbanization (URB) and natural resource depletion (NRD) are incorporated as control variables to mitigate omitted variable bias and isolate the distinct effects of macroeconomic and investment dynamics. Accordingly, two panel regression specifications are estimated:

Model 1:

$$EFP_{it} = \alpha_0 + \alpha_1 GDP_{it} + \alpha_2 GDP^2{}_{it} + \alpha_3 FDI_{it} + \alpha_4 URB_{it} + \alpha_5 NRD_{it} + \mu_{it}, \quad (1)$$

Model 2:

$$CO_{2it} = \beta_0 + \beta_1 GDP_{it} + \beta_2 GDP^2{}_{it} + \beta_3 FDI_{it} + \beta_4 URB_{it} + \beta_5 NRD_{it} + \varepsilon_{it}, \quad (2)$$

where i and t denote country and year, respectively, and μ_{it} and ε_{it} represent the idiosyncratic error terms. The Environmental Kuznets framework is operationalized through the joint estimation of the linear and quadratic GDP terms: a statistically significant positive coefficient on GDP (α_1, $\beta_1 > 0$) coupled with a significant negative coefficient on GDP^2 (α_2, $\beta_2 < 0$) confirms the hypothesized inverted U-shaped relationship. The environmental implications of FDI are assessed through the sign and significance of α_3 and β_3. A positive and significant FDI coefficient indicates that capital inflows exacerbate ecological pressure, thereby supporting the Pollution Haven Hypothesis. Conversely, a negative and significant coefficient suggests that FDI facilitates technological spillovers, managerial efficiencies, and cleaner production practices, lending empirical support to the Pollution Halo Hypothesis.

The empirical analysis utilizes a balanced panel dataset spanning 1990 to 2023 across 17 Asian economies: Bangladesh, China, India, Indonesia, Iran, Japan, Malaysia, Myanmar, the Philippines, Pakistan, Qatar, Saudi Arabia, Singapore, South Korea, Thailand, Turkey, and Vietnam. Sample selection was strictly predicated on data completeness; economies exhibiting missing observations for any variable across the study period were excluded to preserve panel balance and ensure estimator consistency. All macroeconomic and environmental indicators were compiled from the World Bank's World Development Indicators and the Global Footprint Network.

Variable measurement details are summarized in Table 1. Economic growth is measured as real GDP at constant prices, with its squared term explicitly included to capture nonlinear environmental Kuznets dynamics. FDI is quantified as net inflows, typically expressed as a percentage of GDP. Urbanization reflects the annual proportion of the total population residing in urban areas, while natural resource depletion captures the percentage of gross national income (GNI) lost due to the exhaustion of energy, mineral, and forest resources. The ecological footprint, measured in global hectares per capita, accounts for the biocapacity required to sustain a nation's resource consumption and waste assimilation. CO_2 emissions (metric tons per capita) serve as a conventional proxy for atmospheric pollution. The concurrent utilization of these dual environmental metrics enables a robust assessment of how growth and investment dynamics differentially influence aggregate ecological pressure versus sectoral carbon intensity.

To select an appropriate estimator for the panel data, it is essential to conduct various preliminary tests, including the Granger Causality test and the cross-sectional dependence test. This study employs descriptive statistics and correlation analysis to systematically describe the data, with results compared to those from the correlation analysis. Subsequently, the Variance Inflation Factor (VIF) test is conducted to assess the suitability of the explanatory variables as independent variables. The unit root test is the third test, aimed at evaluating the significance of the variables employed. The fourth test, the Engle–Granger cointegration test, examines the linear combination among vari-

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Table 1. Definitions of variables

Variables	Symbols	Definition	Source
Ecological footprint	EFP	The ecological footprint versus biocapacity, measured in global hectares (gha) per person, represents the total amount of global hectares necessary to sustain a country, divided by its population. This metric encompasses built-up land, carbon emissions, cropland, fishing grounds, forest products, and grazing land	Global Footprint Network
Carbon dioxide emission	CO	Carbon dioxide emissions (kt), encompassing gases released from the combustion of fossil fuels and the production of cement, but excluding emissions resulting from land use changes such as deforestation	World Bank
Economic growth	GDP	Gross domestic product (changing in gross domestic product in US$'s constant price)	World Bank
Squared Economic growth	GDP^2	Squared term of economic growth	World Bank
Foreign direct investment	FDI	Net inflow of Foreign direct investment (% of GDP)	World Bank
Urbanization	URB	Urbanization urban population (% of total population)	World Bank
Natural resource depletion	NRD	Natural resource depletion, expressed as a percentage of Gross National Income (GNI), utilizes the aggregate of net forest depletion, energy depletion, and mineral depletion as its measurement unit	World Bank

ables. Fifth, the Granger causality test investigates whether the variables exhibit unidirectional or bidirectional relationships. Additionally, the cross-sectional dependence test is included as the sixth test to verify the presence of cross-sectional dependence within the dataset. The seventh set of tests comprises the Chow, Hausman, and Lagrange Multiplier tests, which facilitate the determination of the most appropriate model for the dataset. Finally, the panel data test is employed as the concluding test in this study, enabling an examination of the interrelationships among the variables.

3. RESULTS

Before presenting the finding for hypotheses testing, the first step is to highlight the results for descriptive statistics (Table 2). This analysis encompasses all variables utilized in this study, with the exception of GDP^2. As indicated by the dataset, Table 2 reveals that among the sample countries, Qatar exhibited the highest Environmental Footprint (EFP) in 2007, whereas Bangladesh recorded the lowest in 1993. In terms of CO_2 emissions, China had the highest level in 2020, while Myanmar had the lowest in 1991. Notably, all variables, except for foreign direct investment and natural resource depletion, have a mean exceeding their respective standard deviations, suggesting that the majority of the results are satisfactory. The correlation analysis indicates that ecological footprint is positively correlated with all other variables, except for CO_2, while CO_2 is negatively correlated with all other variables, except for GDP.

Table 2. Descriptive statistics and correlation analysis results

Variable	EFP	CO_2	GDP	FDI	URB	NRD
Descriptive statistics						
Mean	3.207851	672047.7	904.4368	2.937738	56.87571	3.552418
Median	2.326956	199867.0	239.4969	1.556926	51.88450	1.211549
Maximum	15.97643	10944686	17820.46	32.69117	100.0000	33.45641
Minimum	0.353802	4015.200	0.000000	–2.57440	19.81100	0.000183
Std. Dev.	2.937859	1627985	2038.855	4.550737	25.11709	5.123921
Correlation analysis						
EFP	1.000000					
CO_2	–0.035423	1.000000				
GDP	0.075669	0.827869	1.000000			
FDI	0.212981	–0.061104	–0.125622	1.000000		
URB	0.834347	–0.046674	0.159265	0.237002	1.000000	
NRD	0.500891	–0.103187	–0.183625	0.312396	–0.052736	1.000000

Note: EFP = ecological footprint; CO2 = CO2 emissions; GDP = gross domestic product; FDI = foreign direct investment; URB = urbanization; NRD = natural resource depletion.

The second assessment conducted was the variance inflation factor (VIF) test to verify the appropriateness of the selected explanatory variables by evaluating multicollinearity to ensure the independence of all explanatory variables. The results of this test are presented in Table 3. These findings indicated that the VIF value was less than 5, suggesting the absence of multicollinearity. This confirms that the chosen parameters are appropriate as explanatory variables for EFP and CO_2.

Table 3. VIF (variance inflation factor) results

Variable	Coefficient variance	Uncentered VIF
GDP	0.000001	1.377711
FDI	0.000326	1.615866
URB	0.000005	3.154854
NRD	0.000264	1.813993

Note: GDP = gross domestic product; FDI = foreign direct investment; URB = urbanization; NRD = natural resource depletion.

The unit root test employs the Im, Pesaran, and Shin W-stat tests. The results of these tests indicate that certain variables exhibit non-stationarity at their level form. However, upon taking the first difference, all variables achieve stationarity and statistical significance. As demonstrated in Table 4, all variables become significant at the first difference. Furthermore, the findings suggest that the variables exhibit similar distributions.

The fifth test employed is the Engle-Granger cointegration test, which comprises two statistics: the parametric ADF-statistic panel and the non-parametric PP-statistic panel. As indicated in Table 5, the results for probability statistic demonstrate the existence of cointegration in Model 1 as well as Model 2, as indicated by the probability statistic less than 5 percent.

Building upon the preceding analyses, this study incorporates the Granger causality test as the sixth evaluative measure. Table 6 presents the Granger causality results between the variables in Models 1 and 2. A probability value (Prob) of less than 0.05 indicates a significant influence between the variables, whereas a probability value exceeding 0.05 suggests the absence of such influence. As indicated in Table 6, the coefficients for Model 1 demonstrate that most variables do not exhibit the causality effect to EFP, except NRD. Similarly, in Model 2, there is no evidence for the causality effect to CO_2. In general, there is no indication of the causality effect in both models.

The subsequent analysis focuses on cross-sectional dependence, which should invariably be assessed in studies utilizing cross-sectional data. This necessity arises from the frequent occurrence of

Table 4. Unit root test results from Im, Pesaran and Shin W-stat

Variable	Im, Pesaran and Shin W-stat			
	At Level		At First Difference	
	t-statistics	Probability value	t-statistics	Probability value
EFP	–0.69193	0.2445	–12.5253	0.0000
CO_2	3.17924	0.9993	–6.78119	0.0000
GDP	8.80579	1.0000	–8.36141	0.0000
FDI	–4.13963	0.0000	–14.3921	0.0000
URB	–2.27026	0.0116	–13.0090	0.0000
NRD	–1.02821	0.1519	–12.3524	0.0000

Note: EFP = ecological footprint; CO2 = CO2 emissions; GDP = gross domestic product; FDI = foreign direct investment; URB = urbanization; NRD = natural resource depletion.

Table 5. Engle-Granger cointegration results

Variable	Statistic value	Probability value
Model 1: ***EFP = f (GDP, GDP2, FDI, URB, NRD)***		
Panel PP-Statistic	–14.50788	0.0000
Panel ADF-Statistic	–4.463664	0.0000
Model 2: ***CO_2 = f (GDP, GDP2, FDI, URB, NRD)***		
Panel PP-Statistic	–5.037923	0.0000
Panel ADF-Statistic	–2.625112	0.0043

Note: EFP = ecological footprint; CO2 = CO2 emissions; GDP = gross domestic product; FDI = foreign direct investment; URB = urbanization; NRD = natural resource depletion.

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Table 6. Granger causality results

Model 1: EFP = f (GDP, GDP², FDI, URB, NRD)				Model 2: CO_2 = f (GDP, GDP², FDI, URB, NRD)			
Null Hypothesis:	**Obs**	**F-statistic**	**Prob.**	**Null Hypothesis:**	**Obs**	**F-statistic**	**Prob.**
GDP ≠ EFP	510	1.71215	0.1815	GDP ≠ CO_2	493	15.5274	0.0000
EFP ≠ GDP		0.79970	0.4500	CO_2 ≠ GDP		62.3038	0.0000
GDP² ≠ EFP	510	0.67960	0.5073	GDP2 ≠ CO_2	493	26.7587	0.0000
EFP ≠ GDP²		0.54840	0.5782	CO_2 ≠ GDP2		43.2499	0.0000
FDI ≠ EFP	507	0.88963	0.4115	FDI ≠ CO_2	490	0.06168	0.9402
EFP ≠ FDI		0.92946	0.3954	CO_2 ≠ FDI		0.22533	0.7983
NRD ≠ EFP	490	3.54618	0.0296	NRD ≠ CO_2	490	0.04115	0.9597
EFP ≠ NRD		46.9073	0.0000	CO_2 ≠ NRD		0.93619	0.3928
URB ≠ EFP	510	1.86602	0.1558	URB ≠ CO_2	493	2.69966	0.0682
EFP ≠ URB		0.97454	0.3781	CO_2 ≠ URB		0.85877	0.4243
GDP² ≠ GDP	510	34.9947	0.0000	GDP² ≠ GDP	510	34.9947	0.0000
GDP ≠ GDP²		40.5514	0.0000	GDP ≠ GDP²		40.5514	0.0000
URB ≠ GDP	510	7.25971	0.0008	URB ≠ GDP	510	7.25971	0.0008
GDP ≠ URB		0.92179	0.3985	GDP ≠ URB		0.92179	0.3985
FDI ≠ GDP	507	0.59456	0.5522	FDI ≠ GDP	507	0.59456	0.5522
GDP ≠ FDI		0.35844	0.6989	GDP ≠ FDI		0.35844	0.6989
NRD ≠ GDP	490	0.22758	0.7965	NRD ≠ GDP	490	0.22758	0.7965
GDP ≠ NRD		0.58710	0.5563	GDP ≠ NRD		0.58710	0.5563
URB ≠ GDP²	510	2.71500	0.0672	URB ≠ GDP²	510	2.71500	0.0672
GDP² ≠ URB		0.22196	0.8010	GDP² ≠ URB		0.22196	0.8010
FDI ≠ GDP²	507	0.58244	0.5589	FDI ≠ GDP²	507	0.58244	0.5589
GDP² ≠ FDI		0.16889	0.8446	GDP² ≠ FDI		0.16889	0.8446
NRD ≠ GDP²	490	0.09383	0.9105	NRD ≠ GDP²	490	0.09383	0.9105
GDP² ≠ NRD		0.36261	0.6960	GDP² ≠ NRD		0.36261	0.6960
FDI ≠ URB	507	1.16547	0.3126	FDI ≠ URB	507	1.16547	0.3126
URB ≠ FDI		1.84561	0.1590	URB ≠ FDI		1.84561	0.1590
NRD ≠ URB	490	0.86780	0.4205	NRD ≠ URB	490	0.86780	0.4205
URB ≠ NRD		0.28867	0.7494	URB ≠ NRD		0.28867	0.7494
NRD ≠ FDI	490	0.07445	0.9283	NRD ≠ FDI	490	0.07445	0.9283
FDI ≠ NRD		1.11207	0.3297	FDI ≠ NRD		1.11207	0.3297

Note: EFP = ecological footprint; CO2 = CO2 emissions; GDP = gross domestic product; FDI = foreign direct investment; URB = urbanization; NRD = natural resource depletion.

cross-sectional dependence issues in longitudinal analysis. The findings presented in Table 7 corroborate the presence of cross-sectional dependence within the dataset. This means that there is a certain level of dependence among the observed Asian countries, thereby implying the appropriateness of the first-difference unit root tests for this study.

The subsequent econometric methodology involves conducting the Chow, Hausman, and Lagrange multiplier tests for panel data. As indicated by the results presented in Table 8, among the panel models, the fixed effects model is deemed most suitable. Consequently, the results displayed in Table 9 are derived from the fixed effects model.

The final assessment involves the panel data analysis, which elucidates the interrelationships among the variables under investigation. Table 9 delineates the results of the panel data analysis, underscoring the empirical findings pertaining to the selected variables. In Model 1, EFP serves as the dependent variable, whereas CO2 is the dependent variable in Model 2. This study employs GDP2 to specifically examine the Environmental Kuznets Curve, while the dependent variables, EFP and CO2, are utilized to further explore the applicability of the Pollution Haven Hypothesis and the Pollution Halo Hypothesis within the sample countries. As indicated in Table 9, all variables demonstrate significance for the dependent variables, with the exception of natural resource depletion (NRD) in relation to CO2.

Table 7. Cross-sectional dependence result

Test	Statistic	Probability value
Model 1: ***EFP = f (GDP, GDP², FDI, URB, NRD)***		
Breusch-Pagan LM	1228.457	0.0000
Pesaran scaled LM	65.20914	0.0000
Pesaran CD	3.671380	0.0002
Model 2: ***CO_2 = f (GDP, GDP², FDI, URB, NRD)***		
Breusch-Pagan LM	980.9686	0.0000
Pesaran scaled LM	50.20297	0.0000
Pesaran CD	3.955245	0.0001

Note: EFP = ecological footprint; CO2 = CO2 emissions; GDP = gross domestic product; FDI = foreign direct investment; URB = urbanization; NRD = natural resource depletion.

Table 8. Chow, Hausman, and Lagrange multiplier panel data test results

Model	Chow Test (Prob.)	Hausman Test (Prob.)	Breusch-Pagan Lagrange Multiplier Test (Prob.)
Model 1	0.0000	0.0001	0.0000
Model 2	0.0000	0.0000	0.0000

Table 9. Panel data results

Variable	Coefficient	Std. Error	t-Statistic	Prob.
Model 1: ***EFP = f (GDP, GDP², FDI, URB, NRD)***				
GDP	0.000383	0.0000956	4.001684	0.0001
GDP²	–0.0000000212	0.00000000645	–3.294025	0.0011
FDI	0.065569	0.014127	4.641509	0.0000
URB	0.031232	0.007676	4.068916	0.0001
NRD	–0.035800	0.013331	–2.685538	0.0075
Model 2: ***CO_2 = f (GDP, GDP², URB, FDI, NRD)***				
GDP	1043.029	31.76892	32.83174	0.0000
GDP²	–0.032025	0.002142	–14.94753	0.0000
FDI	–10198.31	4692.291	–2.173419	0.0302
URB	–10433.28	2549.603	–4.092120	0.0000
NRD	4858.800	4427.882	1.097319	0.2730

Note: EFP = ecological footprint; CO2 = CO2 emissions; GDP = gross domestic product; FDI = foreign direct investment; URB = urbanization; NRD = natural resource depletion.

Table 10. Summary of the hypotheses results

Independent variables	Dependent Variables	
	Ecological Footprint (EFP)	Carbon Emission (CO²)
Gross Domestic Product (GDP)	Hypothesis 1 Supported: Significant Positive	Hypothesis 6 Supported: Significant Positive
Squared Gross Domestic Product (GDP²)	Hypothesis 2 Supported: Significant Negative	Hypothesis 7 Supported: Significant Negative
Foreign Direct Investment (FDI)	Hypothesis 3 Supported: Significant Positive	Hypothesis 8 Not Supported: Significant Negative
Urbanization (URB)	Hypothesis 4 Supported: Significant Positive	Hypothesis 9 Not Supported: Significant Negative
Natural Resource Depletion (NRD)	Hypothesis 5 Supported: Significant Negative	Hypothesis 10 Not Supported: Insignificant Positive

Based on the findings in Table 9, a comprehensive summary of hypothesis testing results is presented in Table 10. The summary shows that *H1* to *H7* are supported, whereas *H8* to *H10* are not supported.

4. DISCUSSION

This study examined the impacts of economic growth and foreign direct investment on environmental degradation, measured through environ-

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mental footprint and CO_2 emissions, across a panel of Asian countries from 1990 to 2023. The empirical findings provide nuanced insights into the validity of the Environmental Kuznets Curve hypothesis, the Pollution Haven Hypothesis, and the Pollution Halo Hypothesis, while revealing important heterogeneities across environmental indicators.

The panel fixed-effects results consistently demonstrate an inverted U-shaped relationship between economic growth and both environmental footprint and CO_2 emissions, as evidenced by the positive and statistically significant coefficient on GDP and the negative and significant coefficient on GDP^2 in both models (Table 9). This finding provides robust empirical support for the Environmental Kuznets Hypothesis in the Asian context, aligning with prior studies that have documented similar nonlinear relationships in developing economies (Ahmad et al., 2021; Apergis & Ozturk, 2015; Balsalobre-Lorente et al., 2022; Dong et al., 2018; Naqvi et al., 2023; Pao & Tsai, 2011; Sinha & Shahbaz, 2018; Wang et al., 2022; Zhang et al., 2022). The confirmation of the Environmental Kuznets Curve suggests that, beyond a certain income threshold, economic development in these countries begins to facilitate environmental improvement – potentially through technological advancement, structural economic shifts toward services, and strengthened environmental governance. This result is consistent with Apergis and Ozturk's (2015) analysis of 14 Asian countries, which similarly confirmed the environmental Kuznets using Generalized Method of Moment (GMM) estimation and emphasized the moderating role of institutional quality in shaping the income–emissions nexus. However, the relatively small magnitude of the GDP^2 coefficient warrants caution: while the turning point exists statistically, the pace of environmental improvement post-threshold may be gradual, requiring complementary policy interventions to accelerate decarbonization.

A notable finding is the contrasting effect of urbanization on the two environmental indicators. Urbanization exhibits a positive and significant relationship with ecological footprint but a negative and significant relationship with CO_2 emissions. This apparent contradiction reflects the multidimensional nature of environmental degradation and underscores the importance of indicator selection in environmental economics research. This positive relationship suggests that urban expansion in Asian countries intensifies aggregate ecological pressure through land-use change, resource consumption, and waste generation – findings consistent with recent studies linking urbanization to broader ecological footprint metrics (Hossain, 2011; Islam et al., 2013). Conversely, the negative relationship may reflect efficiency gains associated with urban agglomeration, such as improved public transportation, denser infrastructure, and economies of scale in energy provision. This aligns with emerging literature suggesting that well-planned urbanization can reduce per-capita carbon emissions, particularly in middle-income contexts where infrastructure modernization accompanies urban growth (Chen et al., 2022; Rahman, 2017).

These divergent results echo the mixed findings in the urbanization–environment literature, where some studies report positive associations with emissions while others document negative or nonlinear relationships (Arif et al., 2023; Uddin, 2018). The present analysis suggests that urbanization's environmental impact is indicator-specific: while cities may reduce carbon intensity through efficiency gains, they simultaneously expand overall ecological demand through consumption patterns and spatial expansion.

The FDI coefficients reveal theoretically important heterogeneity. In Model 1, FDI exerts a positive and significant effect on ecological footprint, supporting the Pollution Haven Hypothesis, the proposition that foreign investment flows to jurisdictions with weaker environmental regulations, thereby increasing ecological pressure (Copeland & Taylor, 1994; Javorcik & Wei, 2003). This finding resonates with empirical evidence from developing Asian economies, where FDI has been associated with increased resource extraction and pollution-intensive production (Al-Mulali & Tang, 2013; Benzerrouk et al., 2021; Gill et al., 2018; Huang et al., 2025; Solarin & Shahbaz, 2013).

Conversely, in Model 2, FDI demonstrates a negative and significant relationship with CO_2 emissions, lending support to the Halo Hypothesis, which posits that multinational enterprises transfer cleaner technologies and management practices to host countries (Charfeddine, 2017; Mahmood et al., 2020; Mrabet & Alsamara, 2017). This dual finding suggests that FDI's environmental impact is multidimensional: while foreign investment may intensify aggregate ecological footprint through expanded economic activity, it may simultaneously promote carbon efficiency through technology spillovers and adoption of international environmental standards.

This nuanced interpretation reconciles seemingly contradictory findings in the FDI–environment literature. Recent meta-analyses indicate that the pollution haven effect tends to dominate for broad environmental indicators, while halo effects are more detectable for specific pollutants like CO_2, particularly when host countries possess absorptive capacity for green technology transfer (Demena & Afesorgbor, 2020). The present results underscore the importance of disaggregating environmental outcomes when evaluating FDI's ecological consequences.

The finding for natural resource depletion exhibits a negative and significant coefficient in the first model but an insignificant effect in the second model. The negative relationship between environmental footprint and natural resource depletion is counter-intuitive but may reflect measurement dynamics: countries experiencing rapid resource depletion may simultaneously undergo economic restructuring that reduces certain dimensions of ecological footprint, or the environmental footprint metric may capture compensatory conservation efforts in resource-scarce contexts. This finding contrasts with studies reporting positive associations between resource depletion and environmental degradation (Apergis & Payne, 2009; Apergis & Payne, 2010) but in line with more recent studies (Gokmenoglu et al., 2020; Katircioglu et al., 2018), suggesting that the natural resource depletion–environment relationship is context-dependent and potentially nonlinear. The insignificance of natural resource depletion in the CO_2 model aligns with literature indicating that carbon emissions are more strongly driven by energy consumption patterns and industrial structure than by resource extraction per se (Aller et al., 2021; Zhao et al., 2022). This reinforces the importance of distinguishing between different environmental stressors when designing resource governance policies.

The Granger causality results indicate limited bidirectional causality between the explanatory variables and environmental outcomes, with natural resource depletion showing unidirectional causality toward environmental footprint. The general absence of strong causal linkages suggests that the relationships identified in the panel regression reflect long-run equilibrium associations rather than short-term dynamic adjustments. This finding is consistent with the cointegration results, which confirm long-run relationships among the variables while acknowledging that short-run adjustments may be influenced by country-specific factors, policy shocks, or measurement noise.

The confirmation of cross-sectional dependence (Table 7) validates the use of first-difference unit root tests and fixed-effects estimation, addressing potential bias from unobserved common factors across Asian economies. The absence of multicollinearity (VIF < 5) further strengthens confidence in the coefficient estimates.

The empirical findings yield several policy recommendations for the selected Asian countries. First, policymakers should anticipate that economic growth alone will not automatically resolve environmental challenges (EKC-aware development planning). Active interventions, such as green technology subsidies, environmental taxation, and regulatory strengthening, are necessary to accelerate the transition beyond the environmental Kuznets turning point, as suggested by Shao and Chen (2022) and Wang et al. (2024). Second, there is a need for FDI screening and technology transfer. To harness FDI's potential halo effects while mitigating pollution haven risks, host countries should implement environmental performance standards for foreign investors and strengthen institutional capacity for technology absorption and diffusion, as in line with Wei et al. (2022). Third, policy implication is related to urban planning for co-benefits. Given urbanization's divergent effects on environmental footprint and CO_2, urban development strategies should prioritize compact, transit-oriented design that minimizes ecological footprint while leveraging agglomeration efficiencies for carbon reduction, as stressed by Salman et al. (2022). Fourth, integrated resource–climate governance should be initiated. The complex natural resource depletion findings suggest that resource management policies should be coordinated with climate strategies, recognizing that interventions targeting one environmental dimension may have unintended consequences for others.

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CONCLUSION

This study examines the effects of economic growth and foreign direct investment on environmental sustainability, explicitly testing the validity of the Environmental Kuznets, Pollution Haven, and Pollution Halo hypotheses across a panel of selected 17 Asian economies over the 1990–2023 period. Employing a balanced panel data framework, the analysis controls for urbanization and natural resource depletion to mitigate omitted variable bias and enhance empirical robustness. The results reveal an inverted U-shaped relationship between economic growth and the ecological footprint, thereby providing strong support for the Environmental Kuznets hypothesis. Furthermore, foreign direct investment inflows are positively associated with the ecological footprint but negatively correlated with carbon emissions, indicating the concurrent operation of both the Pollution Haven and Pollution Halo effects. Collectively, these findings underscore the necessity for multidimensional, context-specific environmental policies that account for the complex interplay between economic expansion and ecological degradation. By integrating evidence-based environmental governance with strategic economic planning, policymakers in these economies can effectively reconcile growth–environment trade-offs and accelerate progress toward sustainable development objectives.

AUTHOR CONTRIBUTIONS

Conceptualization: Suyanto Suyanto, Michael Wijaya.
Data curation: Michael Wijaya.
Formal analysis: Suyanto Suyanto, Michael Wijaya.
Funding acquisition: Suyanto Suyanto.
Investigation: Suyanto Suyanto, Michael Wijaya.
Methodology: Suyanto Suyanto, Michael Wijaya.
Project administration: Suyanto Suyanto.
Resources: Michael Wijaya.
Software: Michael Wijaya.
Supervision: Suyanto Suyanto.
Validation: Suyanto Suyanto.
Visualization: Michael Wijaya.
Writing – original draft: Suyanto Suyanto, Michael Wijaya.
Writing – review & editing: Suyanto Suyanto, Michael Wijaya.

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