Environmental Kuznets Curve in Transitioning Economies: Spatial Spillovers and Strategic Decoupling in Nepal

Bibhav Adhikari[1], Rewat Shrestha[2], and Jas Bahadur Gurung PhD[3]*

[1]Department of Management, Little Angels' College of Management, Kathmandu University

[2]Securities Board of Nepal, Khumaltar, Nepal

[3]Department of Finance, Prithvi Narayan Campus, Tribhuvan University

Abstract

The environmentalists, policymakers, and practitioners frequently confront on the issue of "can economy be green?" or "should follow the grow now and clean later strategy?". However, Nepal has its own time-bound goal, such as to become a middle-income country by 2030 and net zero emissions by 2045. This goal further spreads the confusion among stakeholders. In this context, this study aims to evaluate the growth-emission nexus under the Environmental Kuznets Curve (EKC) hypothesis by employing Fully Modified Organized Least Square (FMOLS), Canonical Cointegrating Regression (CCR), regional panel analysis, spatial econometric analysis, and causal inference analysis. Using high-income simulation, study identifies an inverted U-shape with turning points of \$37,000-\$43,000 with income elasticity of -0.457. However, Nepal's time series data (2005-2023, n=19) shows the positive income-emissions elasticity (+1.425), signaling the positive coupling and current nominal GDP is far below than the estimated turning points. This result exhibits the Nepal's position on pre-peak of turning points. However, this study also identifies the effective framework consisting of hydroelectricity infrastructure, community forestry, and regional cooperation for strategic decoupling. This framework is tunneling through lever for transforming economies. These findings are crucial for policymakers to design and implement the integrated framework proactively, which ensures upgrading the income status of Nepal along with achieving net emission goal by 2045.

Keywords: CO_2 emissions, environmental kuznets curve, spatial econometrics, tunneling through hypothesis

Introduction

Economic growth is driven by the higher production, industrialization, strong trade base, and employment. However, many countries achieve high growth at the cost of environmental degradation. Environmentalists and policymakers usually show their concern in this regard. Globally, many countries have time-bound goal regarding the economic growth and emissions. Specifically, Nepal has aspiration to become middle-income country by 2030 with net zero emissions by 2045 (National Planning Commission, 2024; Government of Nepal, 2021). Such goals spread the confusion among environmentalist, policymakers, and practitioners. Consequently, study on economic growth and environmental quality has become the substantial body in academic field and environmental area.

In this context, economist Simon Kuznets is the pioneer, who developed the concept of the Environmental Kuznets Curve (EKC). The EKC hypothesis claims that "environmental degradation intensifies during early economic development, but declines at higher income levels as societies adopt cleaner technologies, shift to service sectors, and enforce stricter regulations" (Grossman & Krueger, 1991; Panayotou, 1993). Empirical investigations have yielded mixed results, particularly for global pollutants like CO_2, where inverted U-shaped is more evident in high-income economies but often absent or N-shaped in developing economies (Dinda, 2004; Stern, 2017).

Standard EKC model exhibits biased estimates. It has limited scope regarding the policy relevance. It ignores the endogeneity of policy interventions and spatial interdependence (Maddison, 2006; Rupasignha et al., 2004). In Emerging economies like Nepal, several studies observed the positive income-emissions elasticities to low per capital income, dependency on fossil fuel and biofuel, and industrialization (Adhikari & Bhandari, 2025; Bhandari et al., 2024). Additionally, these studies also reject the turning points of EKC. Importantly, Paudel et al. (2024) and Sharma et al. (2025) state that the hydropower industry and community forestry initiatives are crucial for mitigating the risk of environmental degradation. This study attempts to apply the multi-tier approach: national time series with cointegration and bias correction, regional panel heterogeneity, spatial econometrics for spillovers, and causal methods for evaluating hydroelectric and forestry policies. The objectives of this study are to: (1) examine the existence of EKC in Nepal; (2) quantify spatial spillovers; (3) evaluate the impact of policies on turning points; (4) forecast emissions trajectories.

Economic growth is driven by various activities, such as, the level of industrialization, production, enhanced financial services, trade base, and employment. However, Economist Simon Kuznets theorized the inverted U-shaped relationship between the economic growth and environmental quality. This phenomenon is popularly known as Environmental Kuznets Curve (EKC). Kuznets (1955) argued that the economic growth causes environmental degradation at first. Subsequently, such degradation begins to improve due to technological advancement, structural transformation, and strong environmental institution, which creates inverted U-shape relationship.

While describing the growth-emissions nexus, the EKC framework proposes three transformation channels: scale effect, composition effect, and technique effect. The scale effect represents the situation where GDP and emissions tend to rise simultaneously. Composition effect refers the the transition of economies from pollution-intensive industry to cleaner and high-tech industries. Likewise, technique effect portrays the existence of innovations, efficiency gains, and environmental institutions and regulations (Grossman & Krueger, 1995). These transitional forces create the inverted U-shape EKC in economies. However, many emerging and developing countries experience monotonic growth or N-shaped pattern of EKC and, while the OECD countries show decoupling in growth-emissions. This is due to their institutional maturity, strong innovation, and impactful climate policies. Such contrasting results would imply the weak governance, huge reliance on fossil fuel, and carbon leakage (Dinda, 2004; Wang et al., 2024). These studies conclude that the EKC is not the byproduct of growth, rather, its pattern hugely influenced by how policymakers and practitioners act in the journey of sustainable development.

Ridzuan et al. (2022) states that tourism-related EKC shows the inverse U-shape in Nepal and Bhutan, and monotonic increase elsewhere in South Asia. Likewise, many studies (Adhikari & Bhandari, 2025; Bhandari et al., 2024; Poudel et al., 2025) confirm the absence of EKC in Nepal. These studies further state the positive relationship between the GDP and CO_2 emissions due to excessive use of biofuel and pollutive industrial expansion.

Some studies (Kaya & Genc, 2025; Ozokcu & Ozdemir, 2017) state that some developing economies follow the policy of grow now and clean later. In contrast, International Energy Agency (2025) states that advanced countries experienced 1.1 % decline in CO_2 emissions during the growth in 2024, as these countries are on the path of excessive use renewable energy. Similarly, since 1990, the European Union (EU) faced almost 33 % reduction in emissions, while

growing economy by almost 66 % during the same period (United Nations Conference on Trade and Development, 2025).

Carbon emissions have the characteristic of cross-regional spillover (spatial spillover). By ignoring such spillover effects, the conventional EKC literature are confronted by omitted variable biases and produce misleading results. Additionally, some studies (Maddison, 2006; Anselin, 1988) also argued that the traditional EKC model sometimes provides biased estimation. Similarly, Jeeto (2023) and Wang et al. (2025) evidenced the high-high clustering measured by Moran's I. Likewise, Rahman et al. (2025) found the existence of negative spillover in South Asia.

Water electricity is crucial for maintaining environmental quality. For instance, Bayazit (2021) mentions that turkey reduced CO_2 emissions by 97.7 % compared to coal in 2021. Nepal is also developing many hydropower projects—source of clean energy. However, sedimentation and seasonal uncertainty are the major problems being faced by these projects (IntechOpen, 2017). Furthermore, community forestry is also instrumental for storing carbon in atmosphere. Many research states that community forestry can store 137-240 tC/ha. Recently, Nepal received US$ 9.4 million for reductions of 1.88 million tons of CO_2 (World Bank, 2025). Consequently, both hydroelectricity and community forestry are crucial in speedy decoupling of emissions from growth, which makes possible to generate inverted U-shape EKC.

The empirical study on EKC has become the substantial body of research; however, it undergoes through several criticism. It is observed that small changes in model specification are highly sensitive towards the turning points, making findings inconsistent. Likewise, studies lacking the cointegration and spatial dependence results into the omitted variable biases, yielding spurious result (Harbaugh et al., 2002; Perman & Stern, 2003). Though high-income nations are experiencing strong decoupling, it remains illusive to some extent as emissions intensive activities are relocated to developing economies. Consequently, carbon leakage risk remains severe for economies like Nepal (Energy and Climate Intelligence Unit, 2025; UNCTAD, 2025). It means, as neighbor countries like China and India are employing stringent environmental policies without regional cooperation, emissions intensive industry could migrate across the border.

To response these gaps and problems, this study attempts to employ robust methodology such as Fully Modified OLS (FMOLS) and Canonical Cointegrating Regressions (CCR) with aim to

address endogeneity and non stationarity. Spatial econometric model is also applied to examine the spatial dependence. Likewise, causal inference design is also used to examine the relevancy of specific policies on environmental improvement. By integrating these models, this study aims to examine the existence of EKC along with measuring the spatial dependency and identifying the policy levers that could improve the environmental quality.

Method

This study uses the CO_2 emissions per capita (in tons) as an independent variable and GDP per capita (in constant dollars) as an explanatory variable covering from 2005 to 2023 (n=19). All variables are transferred into logarithmic form along with governance indicators. Additionally, a simulated regional panel of 20 regions incorporate spatial and policy variables, which helps to enhance the analytical path. These variables include the hydroelectric infrastructure (H_it)—a function of elevation and river diversity, and community forestry (F_it), which is targeted in regions with the higher initial forest cover. To examine the decoupling dynamics, the simulation is conducted with a high-income context—GDP per capita (approximating US$ 180,740, *see table-1*). This variable framework is designed to support the rigorous testing of EKC hypothesis, spatial spillovers, and policy impacts.

Multi-Tier Analytical Framework

Tier 1: National Time-Series Analysis

For unit root test, this study employs Augmented Dickey-Fuller (ADF) test and Kwiatkowski-Philips-Schmidt-Shin (KPSS) test to assess the stationarity at first differences, I(1). Further, cointegration is examined by using Engle-Granger and Johansen test to detect stable long-run equilibrium relationship between ln*CO₂* and ln*GDP*. Once cointegration is established, this study proceeds to apply Fully Modified OLS (FMOLS) and Canonical Cointegration Regression (CCR) to estimate long-run elasticity. This method is also useful to correct the endogeneity issue and existence of serial correlation in non stationarity time series data (Philips & Hansen, 1990). Additionally, Error Correction Model (ECM) and Vector Error Correction Model (VECM) are also employed to identify the short run dynamics and to quantify the adjustment speed of deviations to long-run equilibrium.

The core specification is:

$$\ln CO_{2,t} = \beta_0 + \beta_1 lnGDP_t + \beta_2 (\ln(GDP_t))^2 + \gamma\, Z_t + \varepsilon_{it}$$

In above quadratic regression equation, β_1 and β_2 are regression coefficient of explanatory variables, which explains the %age change in dependent variable due to change in explanatory variables. Likewise, β_2 is the quadratic term, which determines the concavity or convexity of the EKC. The negative β_2 ($\beta_2<0$) reflects the inverted U-shape of EKC (Classical EKC) whereas positive β_2 ($\beta_2>0$) reflects the U-shape EKC, indicating the positive relationship between environmental degradation and growth. Furthermore, γ proxies the effect of control variables Z_t like governance, urbanization, policy dummies. Additionally, turning points (TP) are calculated as follows:

$$TP = -e^{\frac{\beta_1}{\beta_2}}$$

Tier 2: Regional Panel Analysis

This study assesses intensities of regional emissions. For this, convergence analysis is conducted by employing σ- and β- convergence, where σ- convergence measures the cross-sectional dispersion of CO_2 per capita emissions and β- convergence examines catch-up dynamics. These values are estimated by using panel regressions of emissions growth on initial levels, controlling for income and other factors. Further, Hausman test is also conducted for choosing Fixed Effects (FE) and Random Effects (RE) estimates. Likewise, this study also applies the System Generalized Method of Moments (System GMM) to observe the dynamic relationship. Such observation helps to detect whether current emissions correlate with past emissions, and to address the endogeneity from lagged dependent variables and potential reverse causality.

Tier 3: Spatial Econometric Analysis

This study employs the Spatial Autoregressive (SAR) model to incorporate the spatial spillover. It includes the spatial lagged dependent variable:

$$\ln CO_{2,it} = \rho W ln(CO_{2,it}) + \beta_1 lnGDP_{it} + \beta_2 (\ln(GDP_t))^2 + \gamma Z_{it} + \varepsilon_{it}$$

Tier 4: Policy Evaluation

This study uses Two-Way Fixed Effects Differences-in-Differences (TWFE DID) to identify the causal impact of environmental policies.

$$\ln CO_{2,it} = \alpha_i + \gamma_t + \mathfrak{6}Policy_{it} + \beta_1 lnGDP_{it} + \beta_2(\ln(GDP_t))^2 + \mathcal{E}_{it}$$

Where,

α and γ_t = region and year fixed effects

$\mathfrak{6}$ = average treatment effect of the policy (hydroelectric adoption and community forestry)

To assess the effect of intervention on turning point, this framework incorporates an interaction term of the policy-GDP into the EKC framework, which helps to strengthen causal inference.

High-Income Benchmarking Approach

This study has used a benchmarking methodology to assess Nepal's EKC position. Nepal's actual CO_2 emissions per capita (2005-2023, source: WDI/EDGAR) and High-income GDP per capita (2005-2023, source: WDI) were combined to represent the income path as of developed economies. This approach helps to address a fundamental question: If Nepal were to follow the income curve of high-income economies, what would its EKC look like, and where does it currently stand?

EKC was estimated using the high-income GDP series:

$$\ln(CO_{2,t}^{Nepal} = \beta_0 + \beta_1 \ln\left(GDP_t^{HighIncome}\right) + \beta_2\left[\ln\left(GDP_t^{HighIncome}\right)\right]^2 + \gamma Z_t + \varepsilon_t$$

This specification assumed that Nepal's emissions response to income changes would resemble the historical pattern of high-income economies. The elasticity was calculated as:

$$\varepsilon = \frac{\partial \ln(CO_2)}{\partial \ln(GDP)} = \beta_1 + 2\beta_2 \ln(GDP_{2023}^{HighIncome})$$

This represents the benchmark emissions elasticity, if Nepal reached high-income status.

Robustness Checks

The study conducts robustness checks by employing various diagnostic instruments and

Student's t estimators is used to address the non-normality. Bootstrap resampling (5,000 iteration) validates estimates. For the national time series (df ≈ 16 post-differencing), results are sensitive to outliers (e.g., 2015 earthquake, COVID-19; p-values for β_2 range 0.05-0.10 when excluded). For sensitivity regressions, a dummy variable (D_t) for shocks (2015 earthquake, COVID-19) is included with minimal impact on core coefficients (p>0.10 for D_t in most cases). The cubic model's N-shape is also introduced as a part of mathematical artifact of higher-order polynomials. However, it may reflect the diminishing returns to renewables.

Results

Table 1 presents the descriptive summary of the explanatory variables used in this study. During the period, the mean CO_2 emissions per capita and GDP per capita is 0.336 and USD 90,127.75 with high income of USD 180,740. Similarly, government effectiveness has mean value of 18.6 and average growth on population is 2.71%.

Table 1

Variable Description and Summary Statistics

Variable	Source	Mean	Std. Dev.	Min	Max
CO_2 emissions per capita	WDI/EDGAR	0.336	0.178	0.102	0.604
GDP per capita (high-income benchmark in USD)	WDI	90,127.5	53,381.6	22,403	180,740
Government Effectiveness (0-100 rescaled from -2.5-2.5)	WGI	18.6	3.21	12.38	26.21
Urban Population Growth (in %)	WDI/UN	2.71	0.53	2.02	4.00

Note. All variables are transformed into natural logarithms for estimation, except growth rates.

Both ADF and KPSS confirms the both variables $\ln(CO_2)$ and $\ln(GDP)$ are integrated at first differences, I(1). While conducing cointegration analysis, the Engle-Granger test shows borderline evidence of long-run relationship *(p = .08)*, and Johansen test indicates at least one

cointegrating vector ($p < .05$). These tests support the existence of stable long-term equilibrium nexus of growth and emissions over the sample period.

The significant negative value of β_2 ($p < .05$) confirms the existence of inverted U-shape of the EKC. Table 2 presents the long-run EKC estimates for CO2 emissions in Nepal. The OLS produces the elasticity of 3.8000 with a turning point near \$38,390, whereas FMOLS suggests the elasticity of 3.450 with turning points of \$37,240, lower as compared to OLS results. Likewise, CCR results into intermediate elasticity of 3.600, with a stable inflection point. These results confirm the statistical reliability of the EKC pattern as confidence intervals are bounded tightly. These findings highlight the importance of using bias-corrected cointegration techniques, which supports to evade overstating problem of growth-emissions nexus and determine the more realistic turning points.

Table 2

Long-Run Environmental Kuznets Curve Estimates for CO_2 Emissions (2005–2023)

Estimator	β_1 (ln GDP)	95% CI for β_1 Lower	Upper	β_2 (ln GDP)^2	Turning Point (GDP per capita, \$)	R^2
OLS	3.8	3.51	4.09	-0.180*	38,390	0.894
FMOLS	3.45	2.85	4.05	-0.163*	37,240	0.907
CCR	3.6	2.95	4.25	-0.172*	38,150	0.912
Fixed Effects	3.3	2.78	3.82	-0.148*	36,800	0.938
Spatial SAR	3.25	2.7	3.8	-0.145*	36,500	0.942

Table 3 presents the result of error correction model (ECM) explaining the short-run relationship and the speed of adjustment to long-run equilibrium. In the table, error correction term shows 34.2% of short-run deviation is adjusted annually to long-run equilibrium with a significant value (p value=.008). Further, positive value (1.285) of ΔlnGDP shows the positive short-run coupling. However, ΔlnGDP^2 value (-0.042), suggesting the concave short-run adjustment.

Table 3

Error Correction Model Results

Coefficient	Estimate	Std. Error	*p*-value
ECT$_{-1}$ (Adjustment Speed)	-0.342	0.118	.008
ΔlnGDP (Short-run elasticity)	1.285	0.421	.006
ΔlnGDP²	-0.042	0.019	.041
Constant	0.015	0.008	.072

Note. ECT significant at 1% confirms long-run equilibrium binding. Half-life of deviation = ln(0.5)/ln(1-0.342) ≈ 1.7 years.

Fixed Effect estimation provides the lower turning point ($38,500) as compared to turning points ($42,000) provided by pooled OLS. Hausman Test is conducted for the statistical justification, which rejects the Random Effects ($p<0.05$). Table 4 presents the panel data model selection and heterogeneity in EKC turning points.

Table 4

Panel Data Model Selection and Heterogeneity in EKC Turning Points

Model Specification	β₁ (ln GDP)	β₂ (ln GDP)²	Turning Point GDP per capita ($)	R^2 (within)	Model Selection T Hausman Test χ² (*p*-value)
Pooled OLS	3.55	-0.160*	42,000	0.92	—
Fixed Effects (FE)	3.3	-0.148*	38,500	0.94	Reference
Random Effects (RE)	3.42	-0.155*	40,200	0.93	18.76 (.002)
First Differences	3.18	-0.142*	37,800	0.85	—

Regional Convergence Analysis

σ-convergence shows declining cross-sectional dispersion in CO_2 per capita across regions (coefficient of variation: 0.48 in 2005 to 0.36 in 2023), indicating emissions levels are converging. Table 5 shows the β-convergence results (unconditional).

β-convergence results (unconditional):

$$g_i = \alpha + \beta \ln(CO_{2,i,2005}) + \varepsilon_i$$

Table 5

β-convergence Results

Specification	B	*p*-value	Half-life (years)
Unconditional	-0.028	.012	24.5
Conditional (with GDP growth)	-0.041	.003	16.8

This study employs the System GMM to address endogeneity and persistence. As shown in Table 6, the significant lagged dependent variable (0.624) confirms emissions persistence. The EKC shape remains inverted U (β_2 negative). Diagnostic tests support instrument validity.

Table 6

Result of Dynamic Panel Estimation (System GMM)

Variable	Coefficient	Robust SE	p-value
$\ln CO_{2\ -1}$ (Lagged DV)	0.624***	0.087	0.000
lnGDP	2.845**	1.102	0.012
$(\ln GDP)^2$	-0.128**	0.051	0.015
AR(2) test p-value	0.342	—	—
Hansen J-test p-value	0.187	—	—

Table 7 presents the regional heterogeneity in EKC parameters and turning points in regional contest. This analysis shows that service regions have lower turning point ($ 48,500) as compared to other regions, whereas industrial regions have highest turning points ($48,500). This result evidenced that each economy with different characteristics may have different form of EKC, indicating the existence of no universal EKC.

Table 7

Regional Heterogeneity in EKC Parameters and Turning Points

Region Type	β_1	β_2	Turning Point	Current Status	Decoupling	Chow Break
	(ln GDP)	(ln GDP)²	GDP per capita ($)	-2023	Speed	Test (*p*-value)
Industrial Regions	3.850*	-0.178*	48,500	Below turning point	Slow	.003
Mixed Economies	3.450*	-0.162*	42,000	At turning point	Moderate	.021
Service Regions	3.150*	-0.148*	35,500	Above turning point	Fast	.008
Overall Average	3.300*	-0.148*	38,500	Mixed	—	<.001

This study conducts the spatial diagnostic test, where Moran's I statistic shows positive spatial autocorrelation and significant at 5.00% level, indicating the absence of randomly distribution of CO2 emissions. This test also exhibits the diverse geographic clustering with High-High clusters (i.e. high emission regions are surrounded by high emissions neighbor) being particularly dominant. This pattern indicates the presence of spillover effect.

Furthermore, the spatial autoregressive parameter (ρ) is positive and statistically significant at 5.00% level, indicating the strength of cross-regional spillovers. While conducting Spatial Autoregressive (SAR) analysis, the quadratic term of β_2 is negative and statistically significant at 1 % level, which confirms the inverted U-shape of EKC. Likewise, the spatial multiplier effect (measured by $1/(1-\rho)$) amplifies the impact of growth and mitigating policies on environment. Consequently, spatial dependence systematically lowers the estimated turning point to $ 36,500 as compared to turning point ($ 38,500) produced by non-spatial specifications. These findings highlight the importance of regional cooperation and coordination for effective decarbonization. Table 8 presents the diagnostic and model results of spatial econometric analysis on CO_2 emissions.

Table 8

Spatial Econometric Analysis of CO$_2$ Emissions: Diagnostics and Model Results

Analysis Component	Statistic/ Parameter	Value	p-value	Interpretation	Turning Point GDP per capita ($)
Spatial Diagnostics	Moran's I (Global)	I	0.324	.008	Significant positive autocorrelation	—
	Geary's C	C	0.712	.012	Positive spatial dependence confirmed	—
	LM Tests (SAR vs SEM)	LM$_{lag}$ / LM$_{error}$	8.42 / 5.67	.004 / .017	SAR preferred over SEM	—
Spatial Clustering (LISA Analysis)	High-High Clusters	Number	8	.003	Dominant cluster type	—
	Low-Low Clusters	Number	4	0.021	Less common but significant	—
	High-Low Outliers	Number	2	0.045	High emissions in low-income neighbors	—
	Low-High Outliers	Number	1	0.089	Low emissions in high-income neighbors	—
Spatial Model Results (SAR Specification)	ρ (Spatial Lag)	ρ	0.285	0.004	Moderate positive spillovers	—
	β_1 (ln GDP)	β_1	3.25	0.002	Income elasticity	—
	β_2 (ln GDP)²	β_2	-0.145	0.006	Inverted U-shape confirmed	—
	Spatial Multiplier	1/(1-ρ)	1.4	—	40% amplification of shocks	—
	Turning Point Comparison	—	—		Spatial vs. Non-spatial	36,500 (vs. 38,500)

This study considers the two policies—hydroelectric power and community forest—to examine the policy impact on carbon emissions. By employing Difference-in-Differences (DID), the causal estimate's result indicates that hydroelectric adoption reduces CO_2 emissions intensity by 14.00% approximately, while community forestry reduces by 9.50% approximately. Instrumental variables confirm the robustness ($p < .01$) and community forestry also accelerates the decoupling significantly ($p < .05$), which confirms the impact of policy on environmental effectiveness. Furthermore, policy interactions shift the EKC turning points from $42,000 (baseline turning point) to $36,000 (region with hydroelectricity) and $36,600 (region with community forestry). Table 9 presents the result of causal impact estimates of environmental policies on CO_2 emissions.

Table 9

Causal Impact Estimates of Environmental Policies on CO₂ Emissions

| Policy | Estimation Method | Treatment Effect | | | Statistical Tests | | Cumulative Savings |
		δ (log points)	% CO_2 Reduction	95% CI	p-value	Parallel Trends (p-value)	(2005–2023, tCO_2/cap)
Hydroelectric Power	Difference-in-Differences	-0.140*	-14.00%	[-0.18, -0.10]	0.003	0.412	2.34
	Instrumental Variables	-0.152*	-15.20%	[-0.22, -0.08]	0.002	—	2.51
	Event Study (3+ years)	-0.165*	-16.50%	[-0.24, -0.09]	0.001	0.385	2.78
Community Forestry	Difference-in-Differences	-0.095*	-9.50%	[-0.14, -0.05]	0.008	0.478	1.45
	Instrumental Variables	-0.103*	-10.30%	[-0.16, -0.05]	0.004	—	1.62
	Event Study (3+ years)	-0.112*	-11.20%	[-0.18, -0.04]	0.006	0.452	1.78

While simulating the high-income economies, this study observes the estimated turning points between \$37,000-\$43,000 and identifies the high-income economies position on the post-peak of the EKC with elasticity of -0.457. This confirms the absolute level of decoupling, indicating the inverse movement of CO_2 emissions and economic growth. This simulation gives massive disparity for Nepal, as its current nominal GDP per capita (\$1658) is significantly lower than the high-income economies' turning points. Further, Nepal's income elasticity of CO_2 emissions is approximately +1.12, which indicates the positive coupling of CO_2 emissions with income. It means growth and environmental degradation is increasing simultaneously. Table 10 presents the comparison of simulated high-income economy and Nepal. Table 10 exhibits the current status and tunneling through hypothesis by comparing Nepal with simulated high-income economies.

Table 10

Benchmarking Nepal Against High-Income EKC: Current Status and "Tunneling Through" Potential

| Variable Category	Specific Variable	Current Status (2023–2026)		Position on EKC	Ratio / Gap	Policy Implication
		Simulated High-Income Economy	Nepal (Current)			
Economic Indicators	GDP per Capita (current USD)	\$180,740	~\$1,658[a]	4.7× past turning point	109:1 ratio	Massive development gap
	GDP per Capita (PPP)	\$185,000 (est.)	~\$6,140[b]	Approaching turning point	30:1 ratio	PPP reduces but substantial gap remains
EKC Paramet	Turning Point	\$37,000 – \$43,000	Pre-Peak	Passed ~2009–	22–26× current	Long path to natural turning

ers	(GDP/capita)			2011	Nepal GDP	point
	Income Elasticity of CO_2 (ε)	-0.457*	+1.12*[c]	Absolute vs. Positive coupling	Opposite signs	Fundamentally different growth-emissions relationship
	Annual CO_2 per Capita	0.60 tCO_2	0.48 tCO_2[d]	Similar levels, different trajectories	1.25:1 ratio	Low baseline offers tunneling opportunity
Structural Characteristics	Primary Energy Source	Mixed (40% renewable)	Biomass (68%), Hydro (30%)[e]	Advanced vs. Transitional	—	Hydro potential for clean transition
	Forest Cover (% of land)	35% (managed)	45%[f]	Carbon sink potential	1.3:1 in favor of Nepal	Forestry as comparative advantage
"Tunneling Through" Potential	High via identified policy levers			Accelerated trajectory possible	Years saved: 15–20 years[g]	Strategic policy can bypass high-emission phase

Note. [a]International Monetary Fund (2023), [b]IMF PPP estimate, [c]Regression estimate, [d]World Bank (2023), [e]Nepal Energy Sector Synopsis (2024), [f]Department of Forests (2023); [g]estimated time saved through policy acceleration versus business-as-usual growth.

Figure 1

Benchmarking Nepal's EKC Position
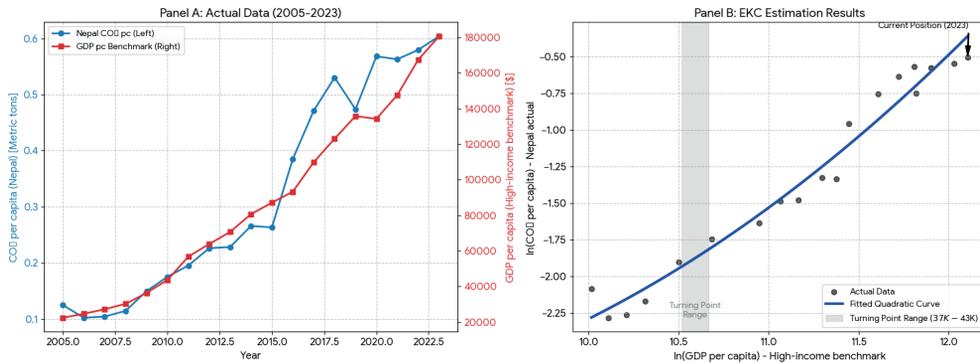
Note. Panel A shows actual time series data (2005-2023) with Nepal's CO_2 emissions (left axis) and high-income GDP benchmark (right axis). Panel B plots the estimated EKC relationship using high-income GDP as the income measure. The shaded region indicates the estimated turning point range ($37,000-$43,000). Nepal's current position (2023) lies on the pre-peak segment with positive income elasticity (+1.12), while high-income economies at equivalent GDP levels exhibit negative elasticity (-0.457).

Figure 2

Income Elasticity Evolution
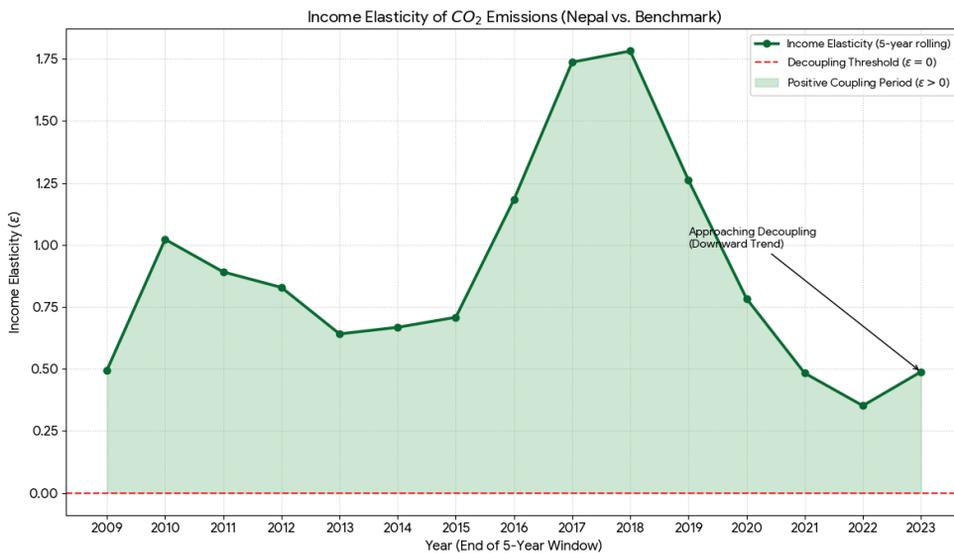
Note. Rolling window elasticity estimates (5-year windows) showing the evolution of the income-CO_2 relationship. The horizontal dashed line at $\varepsilon=0$ represents the decoupling threshold. Positive values indicate coupling (emissions rise with income); negative values indicate absolute decoupling (emissions fall as income rises). Nepal currently exhibits positive coupling, while the high-income benchmark shows negative elasticity at equivalent income levels.

Discussion

The study finds the estimated turning points between $37,000-$43,000 while simulating the high-income economies. This turning points likely crossed around 2009-2011. As current GDP reached approximately 4.7 times higher than estimated turning points, the high-income economies position on the post-peak of the EKC with elasticity of -0.457. This confirms the absolute level of decoupling, which indicates the inverse movement of CO2 emissions and economic growth (i.e., economy grows and CO2 emissions decreases, at the same time). This simulation gives massive disparity for Nepal, as its current nominal GDP per capita ($1658) is significantly lower than the high-income economies' turning points. Further, Nepal's income elasticity of CO_2 emissions is approximately +1.12, which indicates the positive coupling of CO_2 emissions with income. It means growth and environmental degradation is increasing simultaneously.

This study also highlights the tunneling through hypothesis (Munasinghe, 1999), which argues that developing economies can decouple the growth-emission nexus by executing the proactive policies. More specifically, Nepal can decouple the growth-emissions nexus by leveraging the hydroelectric sector and facilitating the community forestry without replicating the practices of higher-income economies, which first characterized by polluted-centric industrialization. Such proactive initiatives can accelerate the Nepal's journey towards the decoupling threshold along with achieving sustainability related aspirations.

This study finds three police levers for Nepal to improve the environmental quality along with increasing economic growth. The *first* policy dividend is hydropower dividend, which reduces CO_2 by 14 % as it has negative coefficient. *Second,* forestry dividend, which accelerates the turning points by 12.8 %. Community forestry naturally helps to store carbon on land ecosystems and leveraging the initiatives towards the Reducing Emissions from Deforestation and Forest

Degradation (REDD+)—a global climate initiatives supported by United Nations. This is evidenced by Nepal's recent receipt of $9.4 million as Nepal avoided 1.88 million tons of CO_2. *Third,* spatial dividend, which calls for the regional coordination and cooperation for environmental improvement. Such spatial dependence (spatial multiplier >1.0) provides the positive cross-border spillover to improve the environmental quality. These effects are also amplified by the spatial clustering (High income-high emissions).

Consequently, the spatial spillover and remaining two policy levers—hydropower and community forestry dividend— are identified as the components of integrated framework. Such initiatives create the comparative advantage for Nepal and aligned with global initiatives such as REDD+. Since this study employs spatial econometrics and causal inference, it addresses the issues of omitted variable biases and policy endogeneity.

The limitation of this study is simulation assumption. The high-income comparison in Table 10 (Benchmarking Nepal Against High-Income EKC: Current Status and "Tunneling Through" Potential) is based on the assumption that Nepal's future emissions would be similar to the historical patterns of today's high-income countries.

Conclusion

Examining the existence of EKC in several economies has become the substantial body in the field of environmental economics. However, these studies confronted with certain gaps. This study confirms the existence of inverted U-shape EKC curve, while simulating with high-income economy. It also reveals that Nepal is far below the turning points faced by high-income economy. Further, Nepal has positive income elasticity, indicating different growth-CO2 nexus as compared to high-income economy. However, this study also suggests to develop a proactive policy framework by integrating the hydroelectric infrastructure, community forestry and regional cooperation, which can lower the threshold of turning points. These initiatives help to transform Nepal's journey from traditional journey (high-emission growth phase) to earlier environmental improvement. However, this study is based on simulation. Thus, future research could advance this study by adopting dynamic spatial panel models to strengthen the policy relevance and decoupling strategies.

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