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Bharat Singh

bharatsingh@gehu.ac.in

Graphic Era Hill University

Rakshit Negi

Graphic Era Hill University

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Growth, Threshold Effects, and the Environmental Kuznets Curve in SAARC Economies: A Heterogeneous Panel Perspective

Bharat Singh*
Ph.D. Scholar, School of Commerce, Graphic Era Hill University, Dehradun, Uttarakhand, India
Email: bharatsingh@gehu.ac.in
ORCID: https://orcid.org/0000-0002-7893-3084
Mobile: +91-9410037965

Rakshit Negi, PhD
Professor, School of Commerce, Graphic Era Hill University, Dehradun, Uttarakhand, India
Email: rakshitnegi@gehu.ac.in
ORCID: https://orcid.org/0000-0003-0776-3011
Mobile: +91-7895014329
***Corresponding author**

Abstract

The study revisits Environmental Kuznets Curve (EKC) hypothesis for a panel of eight SAARC economies spanning 1990-2024. It seeks to examine if the empirical validity of the EKC hypothesis hinges upon the choice of heterogeneous versus homogeneous panel estimators. Accounting for pervasive cross-section dependence (Pesaran CD & bias-corrected LM tests) and rejecting slope homogeneity (Pesaran-Yamagata delta test) across countries, the paper estimates growth-emissions relationship under Pooled Mean Group (PMG), Mean Group (MG), Dynamic Fixed Effects (DFE) and Cross-sectionally Augmented ARDL (CS-ARDL) estimators. Panel estimator choice turns out to be crucial, while the inverted-U shape EKC relationship remains elusive under the homogeneity restrictive PMG and DFE specifications, and significantly robust under CS-ARDL (preferred) estimation ($\beta_GDP = 0.055$, $p<0.01$; $\beta_GDP^2 = -0.018$, $p<0.01$) across all the countries. Panel threshold regression further confirms existence of structural break in growth-emissions relationship at a GDP threshold of approximately 1.74-1.77, implying the EKC turning point estimated earlier. While energy consumption is found to be the most robust predictor of emissions across all specifications, trivariate Granger-causality tests establish the presence of bi-directional growth-emissions and growth-energy feedback effects. Also, uni-directional energy Granger causes emissions throughout the sample period. Methodologically, the findings suggest caution against drawing conclusions about EKC validity in heterogeneous developing-country panels from single estimator studies, particularly those using linear or homogeneity-constrained specifications. This lends support for income-differentiated enforcement of environmental regulations, stricter below the threshold (focus on pollution-abatement), relaxed above it (merit-based focus on technology up-gradation and structural transformation), while expediting regional energy-transition cooperation.

Keywords: *EKC; panel threshold regression; CS-ARDL; SAARC; energy consumption*

1. Introduction

Is economic growth compatible with environmental quality? Or, should policies that protect our planet come at an opportunity cost to development? Perhaps, this remain an important question open to the developmental economists, today. One prominent theoretical response to this is the Environmental Kuznets Curve (EKC) hypothesis. The EKC holds that there is an inverted-U relationship between growth and pollution. Concisely, when per capita income increases environmental degradation first increases and then decreases after reaching some income threshold (Grossman & Krueger, 1995; Panayotou, 1993). Three effects (scale, composition, and technique) are usually held responsible for this shape (Antweiler et al., 2001). However, even after more than three decades of intense research, the empirical validity of the EKC hypothesis remains unconvincing. This is especially true for developing countries, where levels of income, energy infrastructure, and institutional capacity can differ substantially within the same (country) panel.

South Asia is a particularly interesting (and important) region to revisit this question. Home to almost a quarter of the global population, the SAARC regional bloc is considered as one of the most climate-vulnerable regions in the world today (World Bank, 2024), despite having liberalized trade and investment regimes. The CO_2 emissions in the region have increased by an (annual) average of 4.2% over the last two decades (IEA, 2024). Moreover, per capita income ranges from Nepal and Bhutan on the low-income end to India's now-emerging middle-income classification. Taken together, South Asia could be seen as the natural setup for examining the EKC hypothesis. The evidence so far is decidedly mixed for SAARC countries, specifically, the inverted-U has been shown to exist for some (Shahbaz et al., 2019; Murshed & Rashid, 2023), but not others (Allard et al., 2017). Moreover, the choice of pollutant matters just as much as country choice.

For instance, Riaz and Gill (2024) document supportive evidence of the EKC for methane emissions across selected SAARC countries, however, in a recent reassessment of the EKC across CO_2, CH_4, SO_2, NOx, and ecological footprint for this regional bloc (Ali, 2026), using panel-corrected standard errors, no evidence of the EKC has been obtained. This completely undermines the inverted-U results as reported by others in the same body of regional literature. Furthermore, this begs some important questions that are rarely confronted in the literature: Is this disagreement substantive (i.e., do countries and pollutants truly have different growth-emissions relationships?), or does it arise at least in part due to methodological differences, namely the commonly assumed homogeneity of long-run slopes across heterogeneous countries, and the estimator's inherent treatment of cross-sectional dependence?

A significant portion of the panel literature still engages in EKC testing on South Asia using estimators (fixed effects, random effects, FMOLS, DOLS etc.) that either fail to account for cross-sectional dependence (CSD) stemming from regional shocks such as, shared commodity price cycles, monsoon-dependent agricultural fluctuations, regional integration of energy

markets, or that enforce homogeneity of long-run coefficients across countries with severe differences in energy endowments and industrial economies (Pesaran, 2021; Pesaran & Yamagata, 2008). Estimating South Asian panels and other nearby regional panels using second-generation CSD robust methods confirms that neither CSD nor slope heterogeneity are merely idiosyncrasies of these datasets. Azam et al. (2022) confirm CSD and heterogeneous slopes across countries in both the globalization-urbanization-emissions nexus and regional panels from other CSD prone variables using CS-ARDL. This remains true outside of South Asia as shown by the CS-ARDL investigation of Baltic economies (Kar, 2022), revealing that estimator misspecification naive to homogeneity can bias understanding of growth-emissions relations. Given this growing body of evidence and knowing that estimator choice is important, hardly any attempt has been made to systematically compare across the estimator hierarchy for the SAARC panel. Also, to our best knowledge, no study has coupled such a comparison to a formally estimated and bootstrap-validated income threshold (by using panel threshold regression) for all SAARC-member states over the past three decades.

With this background, the present study contributes in three ways. First, it benchmarks the estimated growth-emissions relationship across progressively less restrictive panel estimators (i.e., PMG, MG, DFE, and CS-ARDL). Accordingly, testing with Hausman-style comparisons reveal whether inference on the existence of an EKC pattern holds across alternative homogeneity assumptions built into each estimator. This question is alarming in the light of recent conflicting SAARC results reported using ARDL estimators (Ali, 2026; Riaz & Gill, 2024). Second, the income threshold at which the growth-emissions relationship structurally changes is estimated using panel threshold regression with bootstrapped inference. This can be thought of as providing an estimator-independent cross-check on the turning point value implied by the EKC equation itself. Finally, growth-energy-emissions causality is established using trivariate heterogeneous panel causality tests. Instead of imposing a causal ordering on the variables alone, this technique helps map out the direction and feedback structure of these relationships across a heterogenous panel of economies.

The remainder of the paper is organized as follows. Section 2 reviews the EKC hypothesis' theoretical motivations and its empirical relevance, specifically, for the SAARC. Section 3 details the data and econometric strategy including, diagnostics, estimator ordering, threshold estimation and causality testing. Section 4 presents the empirical findings, followed by discussion in Section 5 and policy recommendations in Section 6.

2. Literature Review

2.1 Theoretical Foundations of the Environmental Kuznets Curve

Empirically, the EKC hypothesis depends on three offsetting channels between income and emissions- the scale, composition, and technique effects (Antweiler et al., 2001). The scale effect states that a larger economy mechanically creates more emissions given its technology and

industrial mix. The composition effect suggests growth causes structural transformation of output away from emission-intensive manufacturing and towards services as incomes increase. The technique effect proposes that growth increases demand for and the affordability of environmental quality leading to cleaner production technologies (Grossman & Krueger, 1995; Panayotou, 1993). While the scale effect dominates at low levels of income leading to increasing emissions with growth, the composition and technique effects are argued to take precedence beyond some income threshold. This generates the EKC's characteristic inverted-U relationship (Shahbaz et al., 2019). Antweiler et al. (2001) implied this logic within a general equilibrium trade framework, showing that the growth-emissions relationship is theoretically ambiguous in sign. This ambiguity arises because the relative strength of each channel depends on a country's factor endowments, trade openness and regulatory stringency- factors which may differ greatly across developing countries. Importantly, the addition of FDI as an extra regressor in the EKC framework is found to shift the turning point. With higher FDI inflows into the more pollution-intensive sectors, the economy can be pushed into a much higher ascending path of the curve (Demena & Afesorgbor, 2020).

2.2 Empirical Evidence on the EKC in South Asia

Empirical support for the EKC in South Asia is decidedly uneven, and recent evidence suggests this disagreement has deepened rather than resolved. Country-level evidence for India and Pakistan has generally favored the inverted-U profile, with estimated turning points clustering in the range of USD 1,500-3,000 per capita in PPP terms (Murshed & Rashid, 2023; Shahbaz et al., 2019). For Bangladesh, Nepal, and Sri Lanka, however, the evidence is considerably weaker, with some studies documenting a monotonically rising emissions-income profile, consistent with these economies still occupying the ascending, pre-turning-point segment of the curve (Murshed & Rashid, 2023; Allard et al., 2017). Pollutant choice compounds this ambiguity, a recent threshold regression evidence for South Asia (Amin et al., 2026) pinpoints the critical mass of CO_2 emissions beyond which the renewable energy transition can support sustainable growth pathways, suggesting a regime-dependent income-environment nexus. While Riaz and Gill (2024) find inconsistent EKC support for methane (CH_4) emissions specifically across SAARC countries, a result that does not track the CO_2-based findings reported elsewhere in the regional literature. Noticeably, a reassessment of the EKC across five pollutants (CO_2, CH_4, SO_2, NOx, and ecological footprint) for the SAARC bloc, using panel-corrected standard errors and Dumitrescu-Hurlin causality, finds no evidence of the EKC at all (Ali, 2026). This is directly contradicting the inverted-U findings reported for individual SAARC countries elsewhere in the literature. This divergence has generally been interpreted substantively, being reflecting genuine cross-country and cross-pollutant differences in industrial structure and energy endowments.

Comparatively little attention has been paid to a competing methodological explanation that studies, reaching opposite EKC conclusions for the same regional bloc, often differ as much in their estimator choice (PCSE versus second-generation panel methods) and substantive findings. This leaves open the question of whether a common panel-wide EKC relationship can be

identified once cross-country heterogeneity is properly modeled with a consistent estimator hierarchy, rather than compared across studies using incompatible methods.

2.3 Cross-Sectional Dependence, Slope Heterogeneity, and Estimator Choice

A separate and largely distinct line of work in panel econometrics has demonstrated that the reliability of long-run growth-emissions estimates depends critically on how two properties of the data are handled: cross-sectional dependence (CSD) and slope heterogeneity. The former refers to the presence of common shocks (e.g., regional monsoon cycles, global commodity price fluctuations, worldwide energy market integration) that lead to correlated error terms across countries. Where present, it invalidates the standard asymptotics underlying first-generation estimators such as fixed effects, FMOLS, and DOLS (Pesaran, 2021). The latter addresses whether the growth-emissions long-run coefficients are truly equal across countries, or change with countries' underlying structural characteristics. Available tests for slope homogeneity (Pesaran & Yamagata, 2008) often reject coefficient equality in developing-country panels with large variations in income. When applied directly to SAARC, the second-generation CSD-robust methods confirm both properties unanimously. Azam et al. (2022) employ CS-ARDL to the SAARC bloc and confirm not only significant CSD but also heterogeneous slopes in the globalization-urbanization-emissions nexus, reaffirming that these are structural features of the regional panel rather than artefacts of any single study's specification. Similar second-generation evidence from other cross-sectional dependency-prone regional panels exists. For instance, CS-ARDL analysis of Baltic economies confirms strong CSD and slope heterogeneity prior to estimating their growth-emissions relationship (Kar, 2022).

This illustrates that the concern is not unique to South Asia but is a general feature of panels combining structurally diverse economies. Estimators developed to jointly address both properties- Pooled Mean Group (PMG) and Mean Group (MG) within the ARDL tradition (Pesaran et al., 1999), and the Cross-Sectionally Augmented ARDL (CS-ARDL) estimator of Chudik and Pesaran (2015) differ sharply in the restrictions they impose. As these estimators embed different (sometimes mutually exclusive) assumptions about the underlying data-generating process, the choice among them is not a matter of statistical convenience but can materially determine whether an EKC relationship is detected at all.

2.4 Threshold Effects and Nonlinearity in the Growth-Emissions Nexus

Subsequent research has moved beyond the gradual, ongoing non-linearity, as suggested by the quadratic EKC framework, to explore if the growth-emissions relationship actually changes discretely once a certain level of economic advancement is reached. Panel threshold regression (Hansen, 1999) captures this notion by permitting coefficients to differ across the regimes defined by an observed threshold variable, with both the threshold's position and its statistical significance being data-driven estimations. This approach continues researchers to push the methodological aspects in studies linking the environment and development. Zaghdoudi (2025),

for example, applies an endogenously determined threshold framework to the relationship between carbon emissions and human development across 54 heavily polluting countries. The finding implies two distinct regimes in which the emissions-development relationship reverses sign around the estimated threshold, illustrating that threshold-based nonlinearity is not confined to the growth-emissions relationship, narrowly. It extends to the related development-environment linkages more broadly, and reinforcing the value of letting the data determines regime boundaries rather than imposing them. Recent applications, specifically to South Asian panels, have identified analogous threshold effects in the relationship between economic activity and emissions, with the estimated turning point offering an estimator-independent cross-check on the income level implied (by quadratic EKC specifications). However, threshold-based evidence for the full eight-country SAARC panel over an extended time horizon, benchmarked directly against a hierarchy of homogeneous and heterogeneous EKC estimators, remains scarce.

2.5 Gaps in the Literature and Contribution

Taken together, three gaps motivate the present study. First, despite recent SAARC-specific evidence reaching opposite EKC conclusions depending on estimator choice using PCSE (Ali, 2026), versus the second-generation CS-ARDL applications (Azam et al., 2022), and comparable regional panels (Kar, 2022), no study has systematically compared the growth-emissions relationship across the full estimator hierarchy (i.e., PMG, MG, DFE, and CS-ARDL) within a single, internally consistent SAARC panel. This is needed to establish CSD-handling assumptions that each estimator imposes in the region, and whether the EKC's apparent validity is an artefact of the homogeneity. Second, despite growing methodological interest in endogenous threshold determination for development-environment relationships (Zaghdoudi, 2025), threshold-based estimates of the income turning point implied by continuous specifications for the complete eight-countries SAARC panel have not been formally cross-validated (within the same study). Third, the causal ordering among growth, energy consumption, and emissions, rather than their contemporaneous correlation alone, has rarely been examined using heterogeneous panel causality methods capable of accommodating country-specific dynamics for the full SAARC panel across multiple pollutant-relevant channels. This study, therefore, attempts to address all these gaps simultaneously by deploying a consistent empirical framework to establish not only whether the EKC is substantively valid in South Asia, but also what are the methodological conditions under which its validity can be detected.

3. Data and Econometric Methodology

3.1 Data and Variable Description

The dataset used for the study is an annual balanced panel of eight SAARC economies, namely Afghanistan, Bangladesh, India, Maldives, Nepal, Pakistan, Sri Lanka, and Bhutan for the period 1990-2024 (T = 35, N = 8, observations = 280). All core variables are sourced from the World Development Indicators (WDI) online database of the World Bank. The dependent variable is the natural log of per capita CO_2 emissions (CE, in metric tonnes). The primary regressors are the natural log of GDP per capita measured in constant 2015 US dollars (GDP) and its square

(GDP^2), included to allow for the inverted-U EKC hypothesis to be tested. The natural log of energy use per unit GDP (EC), the main direct structural driver of emissions in this framework, proxies energy consumption intensity. Net inward FDI (as a percentage of GDP) and a modified Human Development Index (MHDI) are incorporated from the outset strictly as controls in the initial regression, following conventional EKC methodology of accounting for investment and development indicators. However, their estimated coefficients are not analyzed in this context, as concerned environmental impacts (both direct and indirect) are explored in a related study utilizing the identical dataset.

Table 1 reports variable definitions and data sources used by the study.

Table 1
Variable Definitions, Proxies, and Data Sources

Variable	Proxy / Measurement	Source
CE	CO_2 emissions per capita (metric tonnes, log)	World Bank WDI
FDI	Net FDI inflows (% of GDP, log)	UNCTAD FDI Statistics
GDP	GDP per capita, constant 2015 USD$ (log)	World Bank WDI
GDP^2	Square of GDP (EKC test)	World Bank WDI
EC	Energy consumption intensity (log)	World Bank WDI
MHDI	Socio-economic development index (modified HDI via PCA, log)	UNDP; author calculation

Note: All variables are expressed in natural logarithms. The MHDI is normalised to (0, 1) prior to log transformation.
Source: Author's compilation.

3.2 Econometric Strategy

3.2.1 Preliminary Diagnostics: Cross-Sectional Dependence and Slope Homogeneity

Prior to estimation, two pre-tests are conducted to determine the appropriate estimator class. First, cross-sectional dependence (CSD) is tested using the CD test of Pesaran (2004) and the bias-adjusted LM test (Pesaran & Yamagata, 2008), which is preferred in panels with a small cross-sectional dimension (N = 8). In this study's setting, CSD is expected to arise from common regional shocks (e.g., monsoon-linked agricultural cycles, global commodity and oil price movements, and shared energy market integration), which would otherwise bias first-generation estimators. Second, slope homogeneity is tested using the standardized delta (Δ) and size-adjusted delta (Δ_adj) tests of Pesaran and Yamagata (2008), whereby rejection of the homogeneity null (H_0) motivates the use of mean-group-type estimators that permit country-specific long-run coefficients.

3.2.2 Panel Unit Root and Cointegration Testing

Given the likely presence of CSD, second-generation panel unit root tests are employed. The Cross-Sectionally augmented IPS (CIPS) test of Pesaran (2007) and the Cross-Sectionally augmented ADF (CADF) test augment conventional unit root regressions with cross-sectional means to absorb common factor loadings, and yield size-correct inference under CSD. First-generation tests such as Levin-Lin-Chu (LLC) and the standard IPS test are reported alongside these for comparison purposes only. Also, long-run cointegration among CE, GDP, GDP^2, and EC is examined using three complementary tests. The Pedroni (1999, 2004) and Kao (1999) residual-based tests provide within- and between- dimension statistics respectively, despite their

sensitivity to CSD. The Westerlund (2007) error-correction-based test (Gt, Ga, Pt, Pa), which accommodates CSD through bootstrapped p-values and has power against the alternative that only a subset of panel units are cointegrated, is treated as the preferred cointegration test given the heterogeneous SAARC panel.

3.2.3 The CS-ARDL Estimator

The primary estimation strategy is the Cross-Sectionally Augmented ARDL (CS-ARDL) estimator of Chudik and Pesaran (2015), implemented via the xtdcce2 command in Stata (Ditzen, 2021). For country *i* at time *t*, the CS-ARDL model takes the form:

$$\Delta CE_{it} = \alpha_i + \varphi_i CE_{i,t-1} + \beta_i X_{i,t} + \sum_{s=0}^{s} \lambda_{is} \overline{Z}_{t-s} + \varepsilon_{it}$$

where CE_{it} denotes the vector of regressors (GDP, GDP^2, EC, with FDI and MHDI kept as controls), α_i is the country-fixed effect, φ_i is the country-specific error-correction coefficient which should be negative and statistically significant to confirm cointegration, β_i is the vector of long-run coefficients, $\overline{Z}_{t-s}$ is cross-sectional averages of the dependent variable and regressors over s lags (taken as proxies for the unobserved common factors) and ε_{it} is the idiosyncratic error term. Unlike traditional panel approaches, CS-ARDL can account for CSD, slope heterogeneity and mixed-order integration {I(0)/I(1)} in one step by directly purging unobserved common factors and without the need of knowing the cointegration rank a priori. Thus, CS-ARDL represents our preferred specification for testing the EKC hypothesis.

3.2.4 PMG, MG, DFE Estimators and Baseline Model

Within the standard ARDL framework (Pesaran et al., 1999), the Pooled Mean Group (PMG), Mean Group (MG), and Dynamic Fixed Effects (DFE) estimators are presented as a comparative hierarchy. The PMG estimator permits varying short-run dynamics and error variances across countries, while enforcing identical long-run coefficients. In contrast, MG estimates distinct regressions for each unit before pooling their coefficients, thereby imposing no cross-country constraints. Finally, DFE mandates commonality in both short- and long- run coefficients across countries, serving as the fully homogeneous reference benchmark. Hausman (1978) specification tests are used to formally compare PMG with DFE and MG, to test whether the data support the homogeneity restrictions of each estimator. The crucial question this study addresses is whether EKC detection is sensitive to the estimator used.

The baseline long-run model, across all estimator specifications, is estimated as:

$$CE_{it} = \mu_i + \beta_1 GDP_{it} + \beta_2 GDP_{it}^2 + \beta_3 EC_{it} + \beta_4 FDI_{it} + \beta_5 MHDI_{it} + \varepsilon_{it}$$

where μ_i captures country-fixed effects, and ε_{it} is the idiosyncratic error term. A positive and significant β_1 combined with a negative and significant β_2 validates the EKC hypothesis; β_3, β_4 are expected to be positive, reflecting the emissions-intensity of energy use and FDI

inflows. A negative β_5 confirms the hypothesis that socio-economic development attenuates environmental degradation.

3.3 Threshold Regression and Trivariate Causality Testing

Discrete variation in the growth-emissions relationship is formally tested via estimation of a panel threshold regression model (Hansen, 1999) with GDP as the threshold variable. Threshold regression permits the functional coefficients linking regressors to carbon emissions to shift once GDP exceeds an estimated critical value, thereby identifying regime-dependent structural change separate from the continuous, quadratic functional form embodied by the standard EKC specification. The statistical significance of threshold effect is assessed through a bootstrap procedure (300 replications). The estimated threshold value also serves as an estimator-independent cross-check on the income turning point implied by the CS-ARDL estimation.

Furthermore, Dumitrescu-Hurlin (2012) heterogeneous panel Granger causality test is performed for the growth-energy-emissions triad (GDP, EC, CE). The panel causality test establishes direction of casual relationships between the variables. The trivariate specification accounts for the influence of the third variable in each pairwise Granger causality test. This specification reduces omitted-variable bias relative to bivariate analysis and allows causal relationships to vary across countries, which is found appropriate given the panel's confirmed slope heterogeneity. This analysis clarifies whether growth and energy use jointly cause environmental degradation, as well as the presence of any feedback effects among the three variables in the SAARC panel.

4. Empirical Results

4.1 Descriptive Statistics and Correlation Analysis

Descriptive statistics and correlation matrix for main variables are reported in Table 2. The panel mean of per capita CO_2 emissions stands at 0.89 metric tonnes, quite low relative to global averages that reflect higher emission intensities in more developed countries. However, there is significant variation across countries, ranging from a mean of 1.29 metric tonnes per capita in India to 0.24 in Nepal. Even this limited pattern of cross-country variation in outcomes at different stages of development suggests the type of structural heterogeneity that motivates a comparative estimator approach over the single pooled specification.

Table 2
Descriptive Statistics and Correlation Matrix

Variable	Mean	Std. Dev.	Skewness	Kurtosis	CE	FDI	GDP	GDP^2	EC
CE	2.0039	0.0037	1.8450	6.7557	1.000				
FDI	2.0060	0.0111	2.8888	12.5213	0.760	1.000			
GDP	3.4103	0.2597	0.9643	3.3436	0.828	0.730	1.000		
GDP^2	6.2377	0.8743	0.0277	3.3689	0.776	0.665	0.966	1.000	
EC	2.5365	0.2699	-0.2573	2.6760	0.807	0.566	0.761	0.787	1.000

MHDI	1.6846	0.1847	-0.4982	3.3043	0.702	0.526	0.720	0.776	0.774

Notes: Number of observations = 280; Std. Dev. = standard deviation. Descriptive statistics are computed on log-transformed series. Skewness measures asymmetry; kurtosis captures the tail weight of the distribution. *All the correlations are* significant at 1% level. Source: Author's calculations.

Table 2 reassures that all variables are positively correlated with emissions. The highest correlations are with economic growth (0.828) and energy consumption (0.807), suggesting that these are the dominant proximate causes of environmental degradation in the sample. The correlation between GDP and its square is very high (0.966), as would be expected given the nonlinear EKC specification. These simple bivariate relationships motivate but do not substitute for multivariate analysis below, particularly given the cross-country evidence of common shocks and heterogeneous country-specific dynamics described above.

4.2 Cross-Sectional Dependence and Slope Homogeneity

Results of the CSD test are reported in Table 3. Using the Pesaran (2004) CD statistic we can reject the null-hypothesis of cross-sectional independence (CD = 2.691, $p < 0.008$). Table 4 confirms this with bias-adjusted LM test results: both the LM statistic (89.87, $p < 0.001$) and the bias-adjusted LM statistic (22.77, $p < 0.001$) strongly reject the null of cross-panel independence, indicating cross-sectional dependence stemming from common regional shocks (e.g., commodity price cycles and integrated energy markets). In contrast, the unadjusted LM CD statistic is not found significant (-0.484, $p < 0.629$). By considering that the cross-sectional dimension of this panel is small (N = 8), the bias-adjusted statistic is considered as appropriate and more heavily weighted test in making decision. Overall, these results support the use of second-generation, CSD-robust estimators for reliable inference.

Table 3
Pesaran (2004) CD Test Results

Test	Statistic	p-value
Pesaran's test of cross-sectional independence	2.691	0.007
Average absolute off-diagonal element	0.295	-

Note: Null hypothesis: cross-sectional independence. *Source:* Author's calculations.

Table 4
Bias-Adjusted LM Cross-Sectional Dependence Test Results

Test	Statistic	p-value	Decision
LM	89.87	0.000	Reject H_0
LM adj*	22.77	0.000	Reject H_0
LM CD*	-0.484	0.628	Fail to Reject H_0

Note: LM adj* is the bias-corrected LM statistic recommended for small-N panels. LM CD* applies the CD normalisation. Null hypothesis: cross-sectional independence. Greater weight placed on LM and LM adj* for N = 8. *Source:* Author's calculations.

Results of the slope homogeneity test are presented in Table 5. The null hypothesis of slope homogeneity is strongly rejected using both the standardized Delta statistic ($\Delta = 15.413$, $p < 0.001$) and the size-adjusted Delta statistic ($\Delta_ adj = 17.232$, $p < 0.001$). This indicates that the slope coefficient (relating growth and emissions in the long-run) varies significantly across

SAARC countries, plausibly due to cross-country differences in energy mix, industrial composition and development stage. Consequently, estimators that impose slope homogeneity (e.g., DFE) are likely misspecified when applied to this panel, while heterogeneous estimators (MG, CS-ARDL) are preferred for primary analysis.

Table 5
Slope Homogeneity Test (Pesaran & Yamagata, 2008)

Statistic	Value	p-value	Decision
Delta (Δ)	15.413	0.000	Reject H_0
Adjusted Delta (Δ_adj)	17.232	0.000	Reject H_0

Notes: Null hypothesis: slope homogeneity. Rejection confirms heterogeneous long-run relationships across countries. *Source:* Author's calculations.

4.3 Panel Unit Root and Cointegration Results

Tables 6 to 8 present unit root results. First-generation LLC and IPS tests indicate that CE, GDP, and GDP^2 are non-stationary in levels but stationary after first-differencing (I(1)). The second-generation CADF and CIPS tests, which correct for CSD, corroborate this pattern of predominantly I(1) behavior. This mixed but largely I(1) integration profile validates the use of ARDL-family estimators (PMG, MG, DFE, CS-ARDL), which accommodate I(0)/I(1) mixtures without requiring pre-testing of the cointegration rank.

Table 6
First-Generation Panel Unit Root Test Results (LLC and IPS Tests)

Variable	LLC Statistic	IPS Statistic	Integration Order
CE	1.6078	3.1332	I(1)
FDI	-2.2146**	-2.4508***	Mixed / I(0)
GDP	3.8685	5.6917	I(1)
GDP^2	1.7604	3.6561	I(1)
EC	-1.2966*	-0.2864	I(1)
MHDI	-4.2838***	-0.1421	Mixed / I(1)
ΔCE	-14.4732***	-13.6386***	Stationary, I(1)
ΔFDI	-12.5562***	-15.2429***	Stationary, I(1)
ΔGDP	-7.8161***	-9.2840***	Stationary, I(1)
ΔGDP^2	-8.6934***	-10.1490***	Stationary, I(1)
ΔEC	-9.5328***	-9.5298***	Stationary, I(1)
ΔMHDI	-14.2483***	-14.7004***	Stationary, I(1)

Notes: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively. LLC = Levin-Lin-Chu test; IPS = Im-Pesaran-Shin test. Null hypothesis: panels contain unit roots. Δ denotes first difference. *Source:* Author's calculations.

Table 7.
Pesaran (2007) CADF Second-Generation Panel Unit Root Test

Variable	Level *t*-bar	First Difference *t*-bar	Order of Integration
CE	-2.340	-3.847***	I(1)
FDI	-3.045**	-4.549***	I(0)/I(1) Mixed
GDP	-1.732	-4.061***	I(1)
GDP^2	-2.038	-4.061***	I(1)
EC	-2.349	-4.386***	I(1)
MHDI	-3.299***	-3.768***	I(0)/I(1) Mixed

Notes: *** and ** indicate significance at the 1% and 5% levels. Null hypothesis: series contains a unit root. Critical values based on Pesaran (2007). *Source:* Author's calculations.

Table 8
Pesaran (2007) CIPS Second-Generation Panel Unit Root Test

Variable	Level Statistic	First Difference CIPS	Integration Order
CE	-2.114	-5.032***	I(1)
FDI	-3.762***	-5.876***	I(0)/I(1) Mixed
GDP	-1.830	-4.815***	I(1)
GDP^2	-2.018	-4.858***	I(1)
EC	-2.651	-5.950***	I(1)
MHDI	-3.627***	-5.799***	I(0)/I(1) Mixed

Notes: *** indicate significance at the 1% levels. Null hypothesis: series contains a unit root. Critical values based on Pesaran (2007). *Source:* Author's calculations.

Table 9 reports cointegration test results, which are mixed across the three tests employed. The Westerlund (2007) bootstrapped tests fail to reject the null of no cointegration across all four statistics, suggesting no uniform long-run equilibrium holds across the entire panel. The Pedroni (1999, 2004) test provides mixed-support, with some specifications (Phillips-Perron, ADF-based tests) rejecting no-cointegration for some countries while the panel ρ and panel v statistics fail to find any significance. The Kao (1999) test is similarly inconclusive. Rather than being a contradiction, this divergence is expected and consistent with the confirmed CSD and slope heterogeneity, as varied long-run relationships naturally reduce test effectiveness. Consequently, tests striving to identify a singular common cointegrating vector are expectedly limited in their power. This reinforces the appropriateness of estimators such as PMG, CS-ARDL, and threshold regression, which are flexible enough to handle heterogeneous or regime-dependent long-run relationships, rather than insisting on a fixed-equilibrium for all countries.

Table 9
Panel Cointegration Test Results (Dependent Variable: CE)

Test	Statistic	Value	p-value	Robust p-value	Decision
Westerlund (2007)	Gt	-0.664	1.000	0.995	No Cointegration
	Ga	-0.417	1.000	1.000	No Cointegration
	Pt	-3.738	0.903	0.603	No Cointegration
	Pa	-0.750	0.995	0.895	No Cointegration
Pedroni (1999, 2004)	Panel v	-1.155	—	—	No Cointegration
	Panel ρ	0.622	—	—	No Cointegration
	Panel PP	-1.080	—	—	Weak Evidence
	Panel ADF	-0.099	—	—	No Cointegration
	Group ρ	1.166	—	—	No Cointegration
	Group PP	-1.167	—	—	Weak Evidence
	Group ADF	-0.903	—	—	No Cointegration
	PP	-2.653	0.004	—	Cointegration
	ADF	-2.074	0.019	—	Cointegration
Kao (1999)	Modified DF	-0.145	0.442	—	No Cointegration
	DF	-1.258	0.104	—	No Cointegration
	ADF	0.589	0.278	—	No Cointegration
	Unadjusted DF	-5.363	0.000	—	Cointegration

Notes: Null hypothesis: no cointegration. Westerlund test uses bootstrap p-values (400 replications) to account for cross-sectional dependence. Pedroni statistics are asymptotically normally distributed. Kao test assumes homogeneous cointegrating vectors. "Weak Evidence" denotes borderline or inconsistent support. *Source:* Author's calculations.

4.4 Long-Run Estimates: PMG, DFE, MG, and CS-ARDL

Table 10 presents PMG-ARDL estimation results. Energy consumption has a positive long-run impact on emissions that is statistically significant (β = 0.0 179, p < 0.01). The GDP and GDP^2 are not significant under PMG, and thus do not offer strong support for the EKC hypothesis under homogeneity-restricted specification. The error-correction term is negative and statistically significant (ECT = -0.125, p < 0.05), implying that the long-run equilibrium is stable, but adjusts only slowly to shocks (about 13% correction per period).

Table 10
Pooled Mean Group (PMG-ARDL) Estimation Results - Dependent Variable: ΔCE

Variables	Coefficient	Std. Error	z-Statistic
Long-Run			
FDI	0.0491*	0.0287	1.71
GDP	0.0034	0.0069	0.49
GDP^2	-0.0011	0.0026	-0.41
EC	0.0179***	0.0022	8.09
MHDI	-0.0001	0.0027	-0.06
Short-Run Dynamics			
ECT	-0.1252**	0.0579	-2.16
ΔFDI	-0.0079*	0.0044	-1.82
ΔGDP	0.0709	0.0605	1.17
ΔGDP^2	-0.0291	0.0267	-1.09
ΔEC	0.0078***	0.002	3.98
ΔMHDI	-0.0007*	0.0004	-1.75
Constant	0.2320**	0.1073	2.16
Model Statistics		**Value**	
Observations		280	
Number of Groups		8	
Avg. Obs. per Group		35	
Log Likelihood		2019.403	

Notes: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively. ECT = error-correction term. *Source:* Author's calculations.

Table 11 displays the DFE-ARDL estimation outcomes. Under the slope-homogeneity restriction, GDP is positive and significant (β = 0.00 78, p < 0.05), and EC remains the single most important regressor (β = 0.0 161, p < 0.01). While the insignificant GDP^2 hardly provides any support for the inverted-U shaped EKC, the DFE estimate of the error-correction term suggests faster adjustment than PMG (ECT = -0.244, p < 0.01). Hausman testing of PMG vs. DFE (Table 12) fails to reject the null hypothesis of no systematic difference in coefficients between the two estimators. Thus, efficiency considerations lead us to prefer PMG to DFE, while acknowledging that the EKC lacks support from either method when slope homogeneity is enforced.

Table 11
Dynamic Fixed Effects (DFE-ARDL) Estimation Results- Dependent Variable: ΔCE

Variables	Coefficient	Std. Error	z-Statistic
Long-run			
FDI	0.0786***	0.0199	3.96
GDP	0.0078**	0.0039	1.99
GDP^2	-0.0013	0.001	-1.39
EC	0.0161***	0.0018	8.8
MHDI	-0.0067**	0.0029	-2.35
Short-Run			
ECT	-0.2443***	0.0364	-6.71
ΔFDI	-0.0162**	0.0072	-2.26
ΔGDP	0.0043***	0.0016	2.69
ΔGDP^2	0.0004	0.0003	1.52
ΔEC	0.0107***	0.0009	11.49
ΔMHDI	0.0008	0.002	0.39
Constant	0.4393***	0.0664	6.61

Notes: ***, **, and * indicate significance at the 1%, 5%, and 10% levels. ECT = error-correction term. DFE = Dynamic Fixed Effects. *Source:* Author's calculations.

Table 12
Hausman Test Results: PMG versus DFE

Test	Chi-square	p-value	Decision
Hausman Specification Test	0.00	1.0000	Prefer PMG

Notes: Null hypothesis: difference in coefficients is not systematic. Estimated using Hausman PMG DFE, sigmamore alleqs constant. *Source:* Author's calculations.

Table 13 presents a comparison of PMG and MG. Under the fully heterogeneous MG specification (reported in Table 14), EC is again the only significant long-run determinant of emissions ($\beta = 0.0\ 127$, $p < 0.01$), while the speed of adjustment to long-run equilibrium is much faster (~62% per period) than under PMG. This is as expected given the MG's allowance for heterogeneous dynamics at the country level. Once again, neither GDP nor GDP^2 is found to be significant when the MG estimator is used. The Hausman test allows us to decisively reject the null hypothesis that PMG and MG estimation yield equivalent coefficients ($\chi^2 = 51.87$, $p < 0.001$). We conclude that the PMG restriction of slope homogeneity does not hold in this panel, and that MG is therefore the preferred estimator of the two. This result, and earlier rejection of the cross-section restriction of slope homogeneity, motivates us to use the CS-ARDL estimator, which combines MG's accommodation for slope heterogeneity with an explicit correction for the cross-sectional dependence.

Table 13
Hausman Test Results: PMG versus MG

Test	Chi-square	p-value	Decision

Hausman Specification Test	51.87	0.0000	Prefer MG

Notes: Null hypothesis: difference in coefficients is not systematic. Warning: (V_b – V_B) not positive definite is common in dynamic heterogeneous panels and does not invalidate the test given the confirmed slope heterogeneity. Source: Author's calculations.

Table 14

Mean Group (MG-ARDL) Estimation Results - Dependent Variable: ΔCE

Variables	Coefficient	Std. Error	z-Statistic
Long-Run estimates			
FDI	0.0185	0.0226	0.82
GDP	0.1036	0.0700	1.48
GDP^2	-0.0409	0.0317	-1.29
EC	0.0127***	0.0029	4.35
MHDI	-0.0022	0.0044	-0.51
Short-Run estimates			
ECT	-0.6197***	0.0819	-7.57
ΔFDI	-0.0077	0.0068	-1.13
ΔGDP	0.0936	0.0896	1.04
ΔGDP^2	-0.0407	0.0391	-1.04
ΔEC	0.0025*	0.0014	1.80
ΔMHDI	-0.0009	0.0012	-0.70
Constant	1.1547***	0.1594	7.25

Notes: ***, and * indicate significance at the 1%, and 10% levels. MG = Mean Group estimator. *Source:* Author's calculations.

Coefficient estimates from the CS-ARDL estimator are presented in Table 15. GDP has a positive and highly significant impact on emissions in the long run ($\beta = 0.055$, $p < 0.01$). GDP^2 appears to be significantly negative ($\beta = -0.018$, $p < 0.01$), providing confirmation of the EKC once CSD and slope heterogeneity have been adequately addressed. This is in contrast to the previous results that found no evidence of the EKC under both PMG and MG. As before, EC remains the single most robust long-run determinant of emissions across all specifications. The insignificant post-estimation CD statistic ($p < 0.073$) confirms that the estimator successfully absorbs residual cross-sectional dependence.

Table 15

CS-ARDL Long-Run Estimation Results- Dependent Variable: CE

Variables	Coefficient	Std. Error	z-Statistic
FDI	-0.0074	0.0063	−1.17
GDP	0.0552***	0.0172	3.21
GDP^2	-0.0183***	0.0067	−2.73
EC	0.0104***	0.0018	5.92
MHDI	-0.0043	0.0037	−1.18
Model Statistics		**Value**	
Observations		280	
Number of Groups		8	
R^2 (MG)		0.98	
CD Statistic		-1.80	
CD p-value		0.0726	

Notes: *** indicates significance at the 1% level. CS-ARDL estimated using the Common Correlated Effects Mean Group estimator via xtdcce2 (Ditzen, 2021). CD statistic tests for residual cross-sectional dependence. *Source:* Author's calculations.

Table 16 reports CS-ARDL estimates including the lagged dependent variable as an explanatory variable. The lagged dependent variable is positive and highly significant ($\beta = 0.188$, $p < 0.01$), pointing to considerable structural inertia in regional emissions. Coefficients of GDP ($\beta = 0.047$, $p < 0.01$) and GDP^2 ($\beta = -0.017$, $p < 0.01$) maintain their expected signs and statistical significance, while energy consumption remains dominant ($\beta = 0.010$, $p < 0.01$). Table 17 reports the results from error-correction specification. The ECT (-0.849, $p < 0.01$) is negative, highly significant, and unusually large in magnitude. This implies that approximately 85% of short-run disequilibrium is corrected within one year once cross-sectional averages absorb common shocks. Short-run dynamics support the EKC pattern found for the long-run relation (GDP: $\beta = 0.0626$, $p < 0.01$; GDP^2: $\beta = -0.0225$, $p < 0.01$), with energy consumption continued to be the strong short-run driver ($\beta = 0.0103$, $p < 0.01$). The negligible post-estimation CD statistic ($p < 0.95$) confirms near-complete elimination of residual cross-sectional dependence.

Table 16
Dynamic CS-ARDL Estimation Results - Dependent Variable: CE

Variables	Coefficient	Std. Error	z-Statistic
L.CE	0.1875***	0.0449	4.18
FDI	-0.0038	0.0050	-0.75
GDP	0.0474***	0.0153	3.10
GDP^2	-0.0165***	0.0058	-2.82
EC	0.0103***	0.0017	6.05
MHDI	-0.0040	0.0037	-1.09
Constant	0.0015	1.4887	0.00
Model Statistics		**Value**	
Observations		272	
Number of Groups		8	
R^2 (MG)		0.99	
CD Statistic		−1.16	
CD p-value		0.2451	

Notes: *** indicates significance at 1% level. L.CE = first lag of carbon emissions. CD p-value tests for residual cross-sectional dependence. *Source:* Author's calculations.

4.5 Threshold Regression Results

Table 17 points to a statistically significant threshold of 1.7688 (95% CI: [1.7567, 1.7701]) for the GDP-emissions dynamics. As shown by the bootstrap threshold test (Table 18), we can confidently reject the null hypothesis that no threshold exists ($F = 470.52$, $p < 0.001$). These results offer estimator-independent evidence in favor of the existence of a structural break that is qualitatively consistent with the turning point estimated by the CS-ARDL above. Prior to this point, emissions rise due to higher incomes, greater industrialization, and fuel saturation, while beyond it, emissions growth slows as driven by technological progress and structural changes that begin to offset the effects of increased production size.

Table 17
Panel Threshold Regression - Estimated Threshold (Threshold Variable: GDP)

Threshold Model	Estimated Threshold	Lower Bound	Upper Bound
Single Threshold	1.7688	1.7567	1.7701

Notes: Bootstrap replications = 300. *Source:* Author's calculations.

Table 18

Threshold Effect Test (Threshold Variable: GDP)

Threshold Type	RSS	MSE	F-Statistic	p-value	CV (5%)	CV (1%)
Single	0.0001	0.0000	470.52	0.0000	111.72	173.42

Notes: RSS = Residual Sum of Squares; MSE = Mean Squared Error; CV = Critical Value. Bootstrap replications = 300. Source: Author's calculations.

4.6 Trivariate Causality Results

Table 19 reports the Dumitrescu-Hurlin (2012) causality test results for the growth-energy-emissions triad. We find bidirectional causality between growth and emissions (GDP →CE: Z-bar = 6.35, $p < 0.01$; CE→GDP: Z-bar = 3.21, $p < 0.01$). This suggests a feedback structure where economic expansion spurs emissions, and conversely, environmental degradation can negatively impact production expenses and influence industrial policy. The main causal relationship is unilateral and runs from energy consumption to emissions (EC → CE: Z-bar = 4.69, $p < 0.01$). Weak causal relationship from emissions to energy consumption is detected (CE → EC: Z-bar = 1.77, $p < 0.1$), implying that energy use is the principal pathway by which economic growth affects the environment. Additionally, the bidirectional causality between GDP and energy consumption confirms a feedback structure where economic growth necessitates more energy, and the supply of energy impacts production capabilities.

Table 19

Dumitrescu–Hurlin Panel Granger Causality Test - Growth–Energy–Emissions Nexus (Lag = 1)

Null Hypothesis (H_0)	W-bar	Z-bar	p-value	Decision	Direction
GDP does not cause CE	4.1732	6.3464	0.0000	Reject H_0	GDP→CE
CE does not cause GDP	2.6036	3.2073	0.0013	Reject H_0	CE→GDP
EC does not cause CE	3.3453	4.6907	0.0000	Reject H_0	EC→CE
CE does not cause EC	1.8856	1.7712	0.0765	Weak Reject	CE→EC (weak)
GDP does not cause EC	2.9957	3.9913	0.0001	Reject H_0	GDP→EC
EC does not cause GDP	3.8744	5.7487	0.0000	Reject H_0	EC→GDP

Note: Dumitrescu-Hurlin (2012) heterogeneous panel causality test; lag = 1. *Source:* Author's calculations.

5. Discussion

The empirical results determine that SAARC data does not consistently support the existence of the EKC; its manifestation is critically influenced by the chosen panel estimator. Under the homogeneity-restricted PMG and DFE specifications, GDP^2 fails to attain significance and the inverted-U relationship is not confirmed. Under the fully heterogeneous MG estimator, neither GDP nor GDP^2 appeared significant. It is only under CS-ARDL, the estimator that simultaneously relaxes the homogeneity restriction and purges unobserved common factors, the EKC emerges clearly and robustly ($\beta_GDP = 0.055$, $p < 0.01$; $\beta_GDP^2 = -0.018$, $p < 0.01$). This finding is reinforced by both the dynamic CS-ARDL and error-correction specifications. The pattern indicates that prior EKC findings for South Asia based on homogeneity-constrained or CSD-naive estimators may understate the true strength of the relationship, since averaging across countries with genuinely different long-run slopes can obscure a nonlinear pattern that is present but heterogeneous in magnitude across the panel. This most plausibly is stronger for economies such as India and Pakistan, which have already documented country-level EKC evidence, and weaker or absent for economies still on a low-income, pre-turning-point trajectory.

With respect to the threshold regression result, the structural break-point at GDP ≈ 1.74-1.77 coheres with the turning-point predicted by the CS-ARDL quadratic specification. This provides convergent evidence via two different methodologies- one predicated on the presence of a smooth, continuous form of nonlinearity; and the other allowing for the possibility of discrete regime-shift. This indicates that the South Asian economies are passing through a true threshold in their growth-emissions relationship. Next, energy consumption's incidence is robust to inclusion across all estimators (PMG: $\beta = 0.0\ 179$; DFE: $\beta = 0.0\ 161$; MG: $\beta = 0.0\ 127$; CS-ARDL: $\beta = 0.010$; ECM: $\beta = 0.0\ 103$, all $p < 0.01$). Regardless of specification of the growth variable, energy intensity remains the most consistent determinant of regional emissions, as further supported by the pervasive, unidirectional EC→CE causality. Given the South Asia's dependence on coal and biomass for energy generation, this suggests that there is no low-emissions development pathway which does not involve a substantial transition away from dirty energy, irrespective of a country's position along the EKC curve.

Finally, the bi-directional causality between growth and emissions qualifies the policy interpretation resulting from the EKC illustration. If economic growth and emissions (and energy use) reinforce one another in both causal directions, then the downturn in the EKC should not be considered inevitable. If there is no counterbalancing policy to ease the transition between energy sources and clean-up industrial production (i.e., an energy transition policy is absent), then the back-run of causality applies, through which higher emissions lead to higher production costs. This can influence energy/industrial policy choices, suggesting that movement from the upward-sloping to downward-sloping leg of the curve will not automatically happen as a nation passes a certain income level. Instead, it too seems to require active management through structural change and technological upgrading (i.e. the technique-effect).

Taken together, these findings carry two broad implications. Substantively, they support the existence of an inverted-U growth-emissions relationship for the SAARC panel, but one whose descending arm is neither automatic nor uniform across countries, and whose detection is conditional on using estimators that correctly accommodate cross-sectional dependence and slope heterogeneity. Methodologically, they caution against drawing conclusions about EKC validity in heterogeneous developing-country panels from single-estimator studies, particularly those relying on homogeneity-constrained specifications, since the same panel can yield contradictory EKC conclusions purely as a function of estimator choice.

6. Conclusion and Policy Implications

This study has re-examined the EKC hypothesis for eight SAARC economies over 1990-2024, with particular attention to whether its empirical validity depends on the choice of panel estimator. This study confirms the presence of EKC but only under the CS-ARDL estimator, which jointly accommodates cross-sectional dependence and slope heterogeneity. Neither the homogeneity-constrained PMG and DFE estimators nor the fully unrestricted MG estimator detect a statistically significant inverted-U relationship. This estimator sensitivity is itself informative. It demonstrates that inference on EKC validity in heterogeneous developing-country panels may depend as much on methodology as on the fundamental relationship of interest. It warns against placing strong reliance on EKC tests based on single estimators when strong evidence of CSD and slope heterogeneity exists in the panel. Independent confirmation of the

CS-ARDL turning point comes from the panel threshold regression, which locates a break in the growth-emissions relationship. The agreement between these two conceptually different approaches, one fixes a smooth quadratic functional form, while the other allows for a discrete structural break, lends credibility to the notion that this threshold represents a true structural characteristic of the SAARC growth-emissions nexus, as opposed to the consequence of functional-form assumptions.

Adjacently, energy consumption intensity appears to be the single most robust and estimator-invariant predictor of carbon emissions in the sample, maintaining both positive and high statistical significance across all specifications. The finding that a dominant unidirectional causal relationship exists from energy consumption to emissions, coupled with evidence for bidirectional growth-energy and growth-emissions causality, suggests that energy intensity is indeed the primary transmission mechanism through which economic activity impacts the environment in SAARC countries. Furthermore, the causal feedback running both ways between growth and emissions suggests that environmental improvement along the EKC's downward slope should not be taken as mechanistically income-driven.

These findings of the study present at least four policy implications. First, environmental policy in SAARC economies should be explicitly differentiated by income regime rather than applied uniformly across the bloc. Economies operating below the estimated threshold (GDP $\approx$ 1.74-1.77) face a materially higher risk of continued emissions growth from industrial expansion and should adopt more stringent, front-loaded emissions regulations to avoid becoming locked into a pollution-intensive growth path. Economies at or above the threshold are better positioned to prioritize technology upgrading, green innovation, and structural transformation toward lower-emission service- and knowledge-based sectors. Second, given the estimator-robust dominance of energy intensity, an accelerated regional energy transition, away from coal and biomass and towards renewable, should be treated as the single highest-priority climate policy lever for SAARC governments, independent of where individual member states sit on the growth-emissions curve. With renewable electricity generation currently averaging only around 28% regionally (IEA, 2024), regional cooperation on grid integration, cross-border clean energy financing, and coordinated carbon markets could meaningfully lower the cost of this transition relative to unilateral national efforts.

Third, as the growth-emissions and growth-energy relationships are bidirectional rather than unidirectional, policy design should anticipate feedback effects. Measures that reduce energy intensity are likely to moderate future emissions-driven cost pressures on production, and creating a potentially self-reinforcing cycle of improvement, if the initial energy-transition investment is made. Finally, even beyond the SAARC region, our threshold and estimator-robustness results offer a more general methodological point for panel environmental economics. Imposing a linear or otherwise homogenous-slope coefficient on heterogeneous panels of developing countries is likely to lead to biased inference on the growth-environment nexus. At least, future EKC studies using similarly heterogeneous regional panels should report both homogeneity-restrictive and heterogeneity-flexible estimator results prior to confirming or rejecting the EKC hypothesis. Several extensions to this study could also be considered. While using aggregate national GDP hides structural composition, future work could break out growth by sectors (i.e., industry, services, agriculture) to better understand what facets of structural

change may be driving the estimated technique and composition effects. Additionally, employing spatial econometric techniques to account for cross-border pollution spillovers, where energy-intensive output growth in one SAARC economy may be depreciating the air quality of other economies, could prove fruitful for future analysis.

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