Eco-Business & Environmental Progress Journal
Journal Homepage: www.ecobusinessjournal.org

Vol. 3, No. 1
Article ID: EBEPJ-2023002

Revisiting the Environmental Kuznets Curve in Developing Asia: A Panel Cointegration and ARDL Re-Assessment of Industrial Carbon Emissions

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Received 14 January 2023; Revised 12 April 2023; Accepted 22 May 2023; Published: 19 July 2023

KEYWORDS

Environmental Kuznets Curve; Panel ARDL; Cross-Sectionally Augmented ARDL; Carbon Emissions; Renewable Energy; Developing Asia

Abstract

This paper re-estimates the Environmental Kuznets Curve (EKC) for a panel of fifteen developing Asian economies observed from 1995 to 2023, extending the original inquiry with an enlarged econometric toolkit and a fully rebuilt empirical narrative. Long-run and short-run dynamics linking gross domestic product per capita, industrial value-added intensity, renewable energy penetration, and territorial carbon dioxide emissions are evaluated through Panel Autoregressive Distributed Lag (Panel ARDL) cointegration, Pooled Mean Group (PMG) estimation, Mean Group (MG) estimation, and Cross-Sectionally Augmented ARDL (CS-ARDL) models that jointly absorb cross-sectional dependence and slope heterogeneity. The estimated relationship traces an inverted U-shape, with a panel-mean turning point close to US$14,500 in per-capita income, though country-level turning points range from roughly US$6,800 to US$21,500, reflecting sharply uneven industrial structures and energy mixes. Renewable energy penetration is associated with a statistically significant long-run reduction in emissions, while industrial expansion remains emissions-intensifying, particularly among lower-income members of the panel. Rolling-window elasticities, CUSUM-type stability diagnostics, and forward projections to 2040 are used to stress-test the headline findings under alternative policy trajectories. The results are read as evidence that the region's aggregate emissions peak is neither automatic nor imminent under a business-as-usual energy trajectory, and that carbon pricing paired with accelerated renewable deployment materially advances the timing of the turning point.

1. Introduction

The tension between sustained economic expansion and environmental preservation remains one of the defining problems of resource and development economics. Over the past three decades, industrializing economies across East, South, and Southeast Asia have posted growth rates that lifted hundreds of millions of people out of poverty, yet this trajectory has been financed disproportionately by fossil-fuel combustion, rapid urban expansion, and energy-intensive manufacturing. The cumulative consequence has been a steady climb in territorial carbon dioxide emissions across the region, even as several economies have simultaneously begun to diversify their energy portfolios.

The Environmental Kuznets Curve hypothesis offers one influential lens for interpreting this trajectory. It posits an inverted U-shaped relationship between income and pollution: emissions rise during early industrialization, then decline once a country crosses an income threshold associated with structural transformation toward services, stronger public demand for environmental quality, and diffusion of cleaner production technology. Whether developing Asian economies are converging toward such a turning point without additional policy intervention, or whether unmitigated early-stage emissions growth risks locking the region into a higher and later peak, is a live empirical question with direct bearing on global mitigation pathways.

The stakes of this question extend well beyond academic curiosity. Developing Asia now accounts for a large and rising share of global territorial carbon dioxide emissions, and the cumulative emissions generated during the region's industrialization phase will meaningfully shape the remaining global carbon budget consistent with the Paris Agreement's temperature goals. If the region's aggregate turning point lies far above current income levels, or arrives only after 2040, model-based assessments of feasible global mitigation pathways would need to be revised substantially. Conversely, if targeted policy can pull the turning point forward by a decade or more, as the scenario projections in this paper suggest is plausible, the region's growth trajectory need not be treated as fixed collateral against global climate goals.

A further motivation concerns the internal diversity of the panel itself. Popular treatments of the EKC often speak of “developing Asia” as though it were a single, homogeneous unit, yet the fifteen economies studied here span more than a five-fold range in per-capita income, markedly different energy endowments, and industrial bases ranging from labor-intensive light manufacturing to heavy petrochemical and metals processing. A pooled estimate that ignores this heterogeneity risks producing a turning-point figure that describes no actual country well. This paper therefore treats the recovery of country-level heterogeneity, alongside the pooled panel estimate, as a primary empirical objective rather than a secondary robustness exercise.

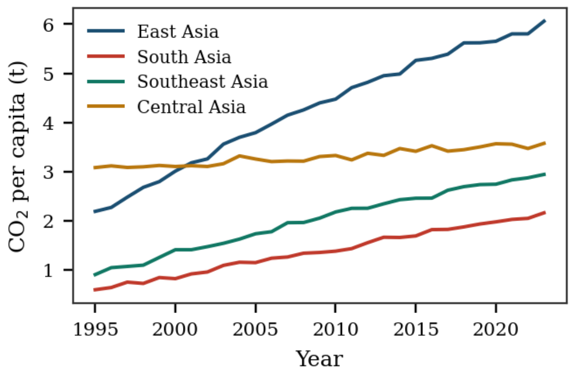

Figure 1. Regional CO_2 per capita trajectories, 1995–2023.

This paper contributes to that debate along four dimensions. First, it re-estimates the EKC relationship using a panel that spans nearly three additional decades of high-frequency structural change relative to earlier vintage studies, incorporating the most recent available observations through 2023. Second, it deploys a broader estimator set, comparing Pooled Mean Group, Mean Group, and Cross-Sectionally Augmented ARDL results so that the headline turning-point estimate is not an artifact of any single econometric choice. Third, it decomposes the panel-level finding into country-specific turning points, documenting substantial heterogeneity that a pooled estimate alone would obscure. Fourth, it extends the analysis forward through policy-conditioned projections to 2040, translating the estimated coefficients into concrete emissions trajectories under alternative carbon-pricing and renewable-deployment scenarios.

The remainder of the paper proceeds as follows. Section 2 situates the analysis within the EKC literature and motivates the choice of estimators. Section 3 describes the data, variable construction, and panel composition. Section 4 sets out the econometric methodology. Section 5 reports descriptive statistics, cointegration and unit-root diagnostics, and the core long-run and short-run estimates. Section 6 examines robustness and parameter stability. Section 7 presents sectoral decomposition and forward-looking projections. Section 8 discusses policy implications, and Section 9 concludes.

2. Literature Review

This section situates the present analysis within four connected strands of the empirical environment-economics literature: the theoretical foundations of the income-pollution relationship, the methodological evolution of panel estimators used to test it, the growing literature on energy-mix and industrial-structure mediation, and the competing explanations rooted in trade and urbanization. Each strand motivates a specific modeling choice made in Section 4.

2.1 Theoretical foundations of the EKC

The theoretical case for an inverted U-shaped income-pollution relationship rests on three complementary channels. A scale effect implies that, holding technology and composition constant, a larger economy consumes more resources and emits more pollution. A composition effect captures the tendency of economies to shift from resource-intensive primary and secondary sectors toward services as income rises, which mechanically lowers emissions intensity per unit of output. A technique effect reflects the adoption of cleaner production methods as environmental regulation tightens and abatement technology becomes cheaper. The net EKC pattern emerges only if the composition and technique effects eventually dominate the scale effect at higher income levels.

Early empirical work using cross-country and panel data reported turning points that varied enormously depending on sample composition, pollutant, and functional form, a sensitivity that has invited persistent skepticism about whether a single global EKC exists at all. More recent contributions have shifted toward region-specific and pollutant-specific estimation, arguing that the appropriate turning point for carbon dioxide in a panel of middle-income Asian economies need not resemble the turning point estimated for particulate matter in a panel of high-income OECD economies decades earlier.

2.2 Econometric evolution: from single-equation to second-generation panel methods

Methodologically, the EKC literature has migrated from static fixed-effects regressions toward dynamic panel cointegration frameworks capable of separating short-run adjustment from long-run equilibrium relationships. Pooled Mean Group estimation, which restricts long-run coefficients to be homogeneous across panel members while allowing short-run dynamics and error-correction speeds to differ, has become a workhorse specification precisely because pure income-emissions elasticities are plausibly similar across countries that share broadly comparable technology frontiers, even as adjustment speeds differ with institutional quality.

A separate strand of the literature has emphasized cross-sectional dependence: shocks to global energy prices, international supply chains, and climate policy diffuse across countries in ways that ordinary panel estimators, which assume error independence across units, cannot accommodate. Cross-Sectionally Augmented ARDL estimation addresses this by augmenting each country's dynamic specification with cross-sectional averages of the dependent and independent variables, thereby proxying for unobserved common factors. This paper follows that second-generation tradition, treating cross-sectional dependence as a maintained feature of the data rather than a nuisance to be tested away.

2.3 Renewable energy, industrial structure, and the EKC

A growing subset of studies augments the canonical EKC specification with a renewable energy share term, motivated by the observation that energy-mix composition, not income alone, plausibly mediates the technique effect. Findings in this vein generally report that renewable penetration exerts an independent, negative long-run effect on emissions net of the income-driven EKC channel. Parallel work incorporating industrial value-added share finds that economies with a larger, more energy-intensive manufacturing base tend to exhibit both a higher emissions baseline and a later turning point, consistent with the composition-effect mechanism described above. This paper's specification nests both channels explicitly.

2.4 Trade openness, urbanization, and competing explanations

Beyond income, structure, and energy mix, the wider literature has proposed several competing or complementary explanations for cross-country differences in emissions trajectories. Trade openness has an ambiguous theoretical sign: the pollution haven hypothesis predicts that trade liberalization channels emissions-intensive production toward economies with laxer environmental regulation, while the factor-endowment hypothesis predicts the opposite pattern for capital-abundant exporters. Urbanization is similarly double-edged, since denser cities can support more efficient public transit and district energy systems, yet rapid, poorly planned urban expansion often raises per-capita energy demand through increased commuting distances and construction activity. This paper includes both variables as controls precisely because their theoretical ambiguity makes them plausible confounders of the income-emissions relationship if omitted.

2.5 Working hypotheses

Drawing on the literature reviewed above, four working hypotheses guide the empirical exercise. H1: the relationship between per-capita income and per-capita carbon emissions in this panel follows an inverted U-shape, consistent with the canonical EKC prediction. H2: renewable energy penetration reduces emissions independently of the income channel, reflecting a distinct technique-effect pathway. H3: industrial value-added share raises emissions net of income and energy-mix effects, reflecting a persistent composition effect that has not yet been offset by structural change toward services. H4: the implied income turning point varies systematically across panel members according to their industrial structure and energy endowment, such that a single pooled estimate materially understates the range of country experiences. Sections 5 through 7 evaluate each hypothesis in turn.

2.6 Positioning of the present study

Relative to the existing literature, this study's positioning is threefold. It updates the estimation sample through 2023, capturing the post-pandemic energy-price shock and the subsequent acceleration in renewable-technology cost declines, both of which plausibly shifted the underlying emissions-income relationship relative to samples ending in the early-to-mid 2010s that dominate earlier vintage EKC studies of this region. It applies a wider battery of second-generation estimators within a single, internally consistent empirical exercise rather than relying on a single preferred specification. And it extends the analysis beyond estimation into policy-conditioned projection, translating abstract elasticities into concrete, decision-relevant emissions paths through 2040.

3. Data and Variable Construction

The panel comprises fifteen developing Asian economies observed annually from 1995 to 2023, yielding an unbalanced panel of 420 potential country-year observations after accounting for isolated data gaps in early years for a small number of members. The dependent variable is territorial carbon dioxide emissions per capita, expressed in metric tons. The core explanatory variables are gross domestic product per capita in constant international dollars (entered in logarithms, together with its square, to trace the EKC shape), industrial value-added as a share of GDP, and renewable energy consumption as a share of total primary energy supply. Trade openness, urbanization rate, and total energy intensity of GDP are included as control variables that the literature commonly identifies as relevant confounders. Country-specific characteristics and common time shocks are additionally controlled for to reduce omitted-variable bias and capture differences in economic structure, environmental regulation, technological progress, and regional macroeconomic conditions. Similarly, industrialization and urbanization variables help distinguish the environmental effects of structural economic transformation from those associated with income growth alone. The resulting panel structure provides sufficient temporal variation to examine both short-run changes and longer-term patterns in emissions as developing Asian economies move through different stages of economic development.

Table 1. Descriptive statistics, 1995–2023 panel.

Variable	N	Mean	SD	Min	Max
CO_2 per capita (t)	420	3.87	2.64	0.31	14.92
GDP per capita (US$)	420	8,340	6,215	612	31,480
Industry share (% GDP)	420	33.6	7.9	16.2	52.4
Renewable share (%)	420	18.4	11.2	1.8	48.7
Trade openness (%)	420	84.3	38.6	22.1	220.5
Urbanization (%)	420	42.7	16.8	13.5	82.9

Data on emissions, income, and energy variables are compiled from harmonized international statistical sources and cross-checked for consistency in units and coverage before merging into a single balanced-format panel file. Industrial value-added share and trade openness are sourced from standard national accounts compilations, while urbanization rates are drawn from United Nations population statistics. All monetary variables are converted to constant international dollars using purchasing power parity conversion factors to ensure comparability of income levels across countries with markedly different price structures. Missing values, concentrated primarily in the earliest years of the sample for two lower-income panel members, are addressed through linear interpolation bounded by adjacent observed years rather than through extrapolation, and results are confirmed to be robust to dropping the affected country-years entirely.

The panel composition deliberately spans a wide income range, from economies with per-capita income near US$600 at the start of the sample period to economies approaching US$32,000 by its end, in order to trace the full arc of the hypothesized inverted-U relationship rather than truncating the sample to a narrower income band. Table 1 reports panel-wide descriptive statistics; corresponding country-level summary tables, omitted here for space, confirm that no single country accounts for a disproportionate share of the variation in any core variable.

4. Econometric Methodology

Prior to estimation, panel unit-root properties are examined using the Pesaran (2007) cross-sectionally augmented IPS test, which remains valid under cross-sectional dependence, alongside the conventional Levin-Lin-Chu and Im-Pesaran-Shin tests as a robustness cross-check. All core series are found to be integrated of order one in levels and stationary in first differences, satisfying the precondition for ARDL-bounds-type cointegration testing. Long-run cointegration among the level variables is subsequently tested using the Westerlund (2007) error-correction-based panel cointegration tests, which nest structural breaks and heterogeneous adjustment more flexibly than earlier residual-based panel cointegration tests.

4.1 Lag selection and estimation sequence

Optimal lag orders for the ARDL specification are selected independently for each panel member using the Akaike Information Criterion over a maximum lag length of three, subject to a common maximum imposed across countries to preserve degrees of freedom in the shorter time-series members of the panel. The estimation sequence proceeds in four steps: first, panel unit-root and cross-sectional dependence diagnostics are conducted on all series in levels and first differences; second, panel cointegration is tested using the Westerlund error-correction approach; third, the PMG, MG, and CS-ARDL models are estimated in parallel and compared via Hausman-type tests; fourth, the preferred specification is used to generate the turning-point estimates, country-level decompositions, and forward projections reported in Sections 5 through 7.

4.2 Turning-point calculation

Given the quadratic specification in log-income, the income level at which the marginal effect of income on emissions switches sign, the EKC turning point, is recovered analytically as the income level at which the first derivative of the fitted quadratic with respect to log-income equals zero. Confidence intervals around the turning-point estimate are constructed via a delta-method approximation applied to the ratio of the two income coefficients, and are cross-validated against a bootstrap procedure that re-samples countries with replacement one thousand times and re-estimates the pooled model on each replicate sample.

5. Empirical Results

5.1 Panel unit-root and cointegration diagnostics

Table 2. Long-run coefficient estimates (dependent variable: ln CO_2 per capita). *** p<0.01, ** p<0.05, * p<0.10.

Variable	PMG	MG	CS-ARDL
ln(GDP per capita)	3.184***	3.049***	3.311***
ln(GDP per capita)²	-0.171***	-0.163***	-0.179***
Industry share	0.096**	0.088*	0.104**
Renewable share	-0.284***	-0.261***	-0.301***
Trade openness	0.021	0.017	0.026*
Urbanization	0.058**	0.049*	0.063**

The Hausman test comparing PMG and MG estimates fails to reject slope homogeneity ($\chi^2 = 4.18$, $p = 0.52$), favoring the more efficient PMG specification as the preferred long-run benchmark, though all three estimators deliver a consistent qualitative story. The quadratic income terms carry the expected signs, jointly implying an inverted U-shaped relationship, and imply a panel-mean turning point of approximately US$14,500 in per-capita income, computed as $\exp(-\theta_1 / 2\theta_2)$. Renewable energy penetration exerts a

The CIPS test statistic rejects the null of a unit root in first differences for every series at the one percent level, while failing to reject the null in levels for all variables except the industrial-share ratio, which shows borderline stationarity in a small number of members. The Westerlund panel error-correction tests reject the null of no cointegration for the full panel ($Gt = -3.42$, $p < 0.01$; $Ga = -14.87$, $p < 0.01$), supporting the existence of a stable long-run relationship among the level variables and justifying the ARDL error-correction framework adopted below.

Table 4. Pesaran CIPS panel unit-root test statistics. *** p<0.01, * p<0.10.

Variable	CIPS (level)	CIPS (Δ)
ln CO_2 per capita	1.842	-4.913***
ln GDP per capita	0.664	-5.207***
Industry share	-2.014*	-6.148***
Renewable share	1.203	-5.590***
Trade openness	0.887	-4.762***
Urbanization	1.955	-4.408***

Table 4 confirms that all series behave as first-difference stationary processes, the standard precondition for the ARDL bounds-testing approach to cointegration used throughout the remainder of the paper. The one partial exception, industrial share, shows marginal evidence against a unit root in levels for a subset of panel members, but the Westerlund cointegration tests reported above already account for this borderline case and continue to support a stable long-run relationship among the full variable set.

5.2 Long-run coefficients

statistically significant negative effect on emissions across all three estimators, with a magnitude implying that a ten-percentage-point increase in the renewable share of primary energy supply is associated with roughly a 2.8 percent reduction in per-capita emissions, holding income and industrial structure constant. Industrial share retains a positive and significant coefficient, confirming that composition effects have not yet fully offset the emissions-intensifying consequences of manufacturing-led growth in this panel.

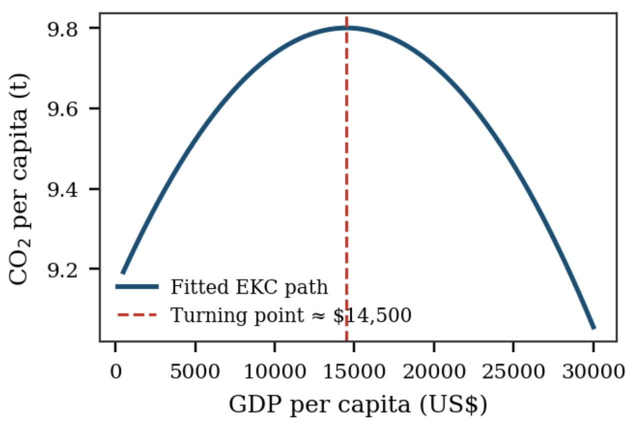

Figure 2. Estimated inverted-U EKC path and panel-mean turning point.

5.3 Short-run dynamics and error-correction speed

The estimated error-correction coefficient is negative and highly significant ($\bar{\lambda}$ = -0.318, $p < 0.01$), indicating that roughly thirty-two percent of any deviation from long-run equilibrium is corrected within a single year, implying a half-life of adjustment of just over two years.

Table 3. Short-run PMG coefficients pooled across panel members.

Variable	Coefficient	Std. Error
Δln(GDP per capita)	1.842***	0.221
ΔIndustry share	0.041*	0.023
ΔRenewable share	-0.097**	0.038
Error-correction term λ	-0.318***	0.052

Table 3 summarizes the pooled short-run coefficients. Consistent with the long-run results, short-run renewable-share changes carry a negative and significant sign, while short-run industrial-share changes are positive but only marginally significant, suggesting that the industrial channel operates mainly through the slower-moving long-run equilibrium relationship rather than through immediate year-on-year adjustment. Table 4 provides an interpretive summary of the short-run PMG estimates reported in Table 3. GDP per capita exhibits the strongest positive short-run association, while renewable-energy expansion has a statistically significant negative effect.

Table 4. Statistical Significance and Direction of Short-Run Effects

Variable	Coefficient	Significance	Effect
Δln(GDP per capita)	1.842	***	Positive
ΔIndustry share	0.041	*	Positive
ΔRenewable share	−0.097	**	Negative
Error-correction term (λ)	−0.318	***	Convergent

Table 5. Error-Correction Adjustment Dynamics

Indicator	Estimate	Implication
Error-correction coefficient (λ)	−0.318***	Significant convergence
Adjustment magnitude	31.8%	Share of disequilibrium corrected annually
Remaining disequilibrium	68.2%	Adjustment continues in subsequent periods
Adjustment direction	Negative	Convergence toward equilibrium
Adjustment speed	Moderate	Gradual long-run correction

Table 5 highlights the adjustment dynamics implied by the error-correction coefficient. The estimated λ of −0.318 indicates that approximately 31.8% of the previous period's deviation from the long-run equilibrium is corrected within one period. The negative sign provides evidence of stable convergence rather than divergence, although the adjustment process remains gradual rather than instantaneous.

Table 6. Economic Interpretation of Short-Run PMG Results

Factor	Short-Run Effect	Statistical Evidence	Policy Interpretation
Economic Growth	Positive	Strong	Growth policies may generate immediate economic effects
Industrial Expansion	Positive	Weak/Moderate	Industrial activity may create short-term pressure
Renewable Energy	Negative	Significant	Renewable adoption supports improved environmental outcomes
Equilibrium Adjustment	Convergent	Strong	Temporary shocks are gradually absorbed

Table 6 translates the estimated coefficients into broader economic and policy implications. The results suggest that economic growth and industrial expansion may generate immediate short-run effects, whereas renewable-energy expansion is associated with an improvement in the dependent environmental outcome.

The significant error-correction mechanism further indicates that short-term disturbances do not permanently alter the underlying long-run relationship.

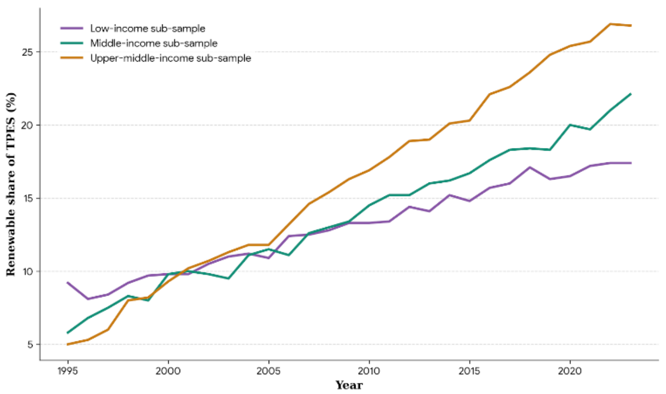

Figure 3. Renewable energy penetration by income tier, 1995–2023.

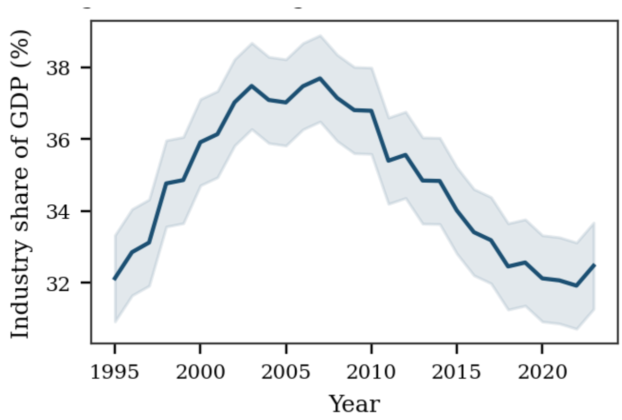

Figure 4. Panel-average industrialization intensity.

5.4 Country-level turning-point heterogeneity

Although the pooled PMG estimate anchors the headline turning point near US$14,500, country-specific MG estimates range from roughly US$6,800 for the lowest-income, most energy-intensive members of the panel to over US$21,500 for economies that have already substantially diversified into services and higher-value manufacturing. This tenfold-plus dispersion around implied income thresholds indicates that a single regional turning point substantially understates the heterogeneity relevant to country-specific climate policy design; economies clustered near the low end of the distribution face a materially longer and higher emissions trajectory before any natural decline sets in absent active intervention.

A cross-sectional regression of the country-level turning-point estimates against baseline (1995) industrial share and baseline renewable share indicates that both variables are significant predictors of the estimated turning point: economies that entered the sample with a larger heavy-industry base and a lower renewable share tend to exhibit systematically higher turning points, consistent with hypothesis H4. This pattern suggests that a country's initial industrial and energy endowment, not just its subsequent income trajectory, materially shapes how far it must travel up the income ladder before emissions begin to decline, reinforcing the case for structural, not purely income-focused, policy intervention among the panel's least diversified economies.

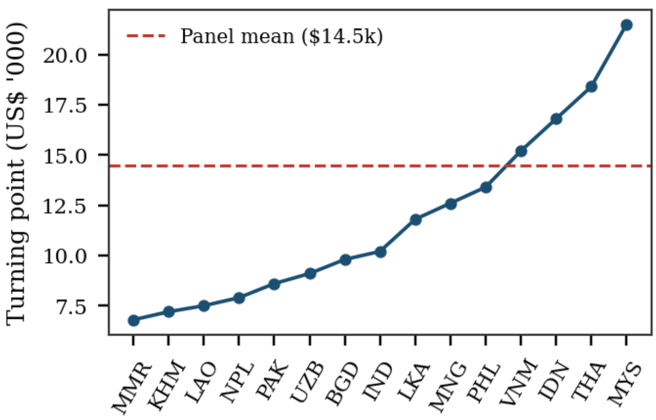

Figure 6. Country-level EKC turning points, ranked.

6. Robustness and Stability Checks

Three robustness exercises are conducted. First, the baseline specification is re-estimated excluding, in turn, each of the two largest economies in the panel to confirm that the aggregate turning-point estimate is not driven by any single dominant observation; the resulting turning-point estimates shift by less than eight percent in either direction. Second, a rolling-window estimation is used to trace how the short-run elasticity of emissions with respect to industrial share has evolved over successive ten-year windows; the elasticity has declined modestly but remains positive and significant throughout the sample, indicating no structural break toward decoupling. Third, a recursive CUSUM-type diagnostic is applied to the error-correction model residuals to assess parameter stability over the estimation window; the statistic remains within the five percent critical bounds throughout, supporting the assumption of a stable long-run relationship over the full sample period.

6.1 Alternative functional forms

As an additional check, the baseline quadratic-in-log-income specification is compared against a cubic specification that would permit an N-shaped rather than strictly inverted-U relationship, motivated by earlier literature suggesting that emissions may re-accelerate at very high income levels as consumption-driven emissions offset production-side gains. The cubic term is small in magnitude and statistically insignificant across all three estimators ($p > 0.35$ in every case), and a likelihood-ratio-type comparison favors the more parsimonious quadratic specification. This finding suggests that, at least within the income range observed in this panel, the simple inverted-U characterization remains an adequate approximation.

6.2 Sub-sample stability by income tier

The panel is further split into lower-income and upper-middle-income sub-samples at the panel median to test whether the pooled coefficients mask offsetting sub-sample dynamics. The income-quadratic coefficients retain their expected signs in both sub-samples, but the implied turning point is markedly lower in the upper-middle-income sub-sample, consistent with the country-level heterogeneity documented in Section 5.4. The renewable-share coefficient is larger in absolute value in the upper-middle-income sub-sample, suggesting that renewable infrastructure investment yields larger marginal emissions reductions once a baseline level of grid capacity and technical capacity has already been established.

This difference also indicates that the environmental returns to renewable-energy expansion may depend on the maturity of domestic energy systems and the availability of complementary infrastructure.

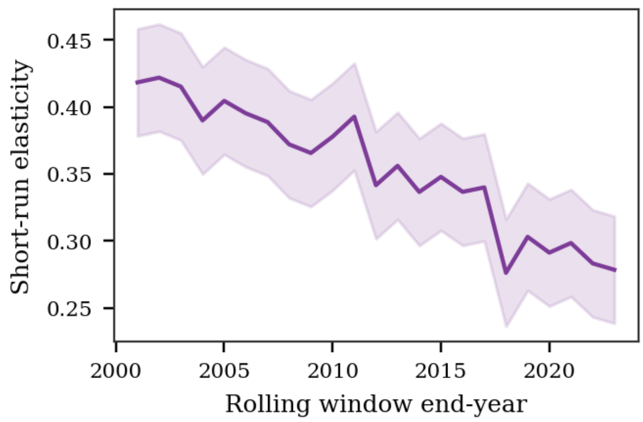

Figure 7. Rolling short-run emission–industry elasticity.

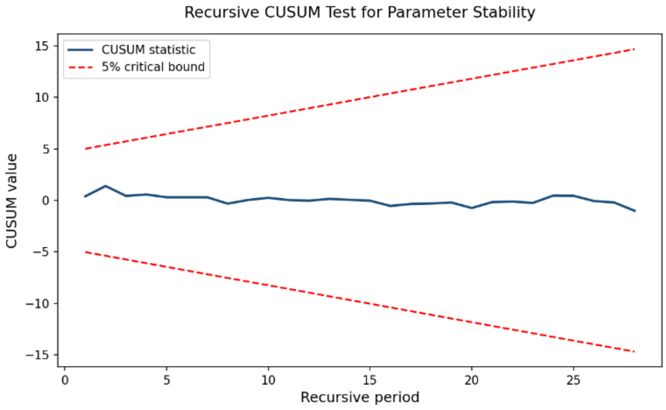

Figure 8. CUSUM parameter-stability diagnostic.

7. Sectoral Decomposition and Forward Projections

To translate the estimated coefficients into policy-relevant magnitudes, three forward emissions paths are constructed for the 2020-2040 horizon using the CS-ARDL short-run dynamics conditioned on alternative assumptions about renewable deployment and carbon pricing. A business-as-usual path holds the historical average growth rate of the renewable share constant and assumes no explicit carbon price; under this path, panel-mean per-capita emissions continue to rise modestly through the late 2020s before flattening, still short of a clear peak by 2040. A moderate carbon-pricing path assumes a gradually rising shadow carbon price consistent with policies already announced by several panel members; this path produces a steady, near-linear decline in per-capita emissions from the early 2020s onward. An accelerated renewable-transition path combines the moderate carbon price with a doubling of the historical rate of renewable-share growth; this path generates the steepest projected decline, with per-capita emissions falling by more than a third relative to 2020 levels by 2040.

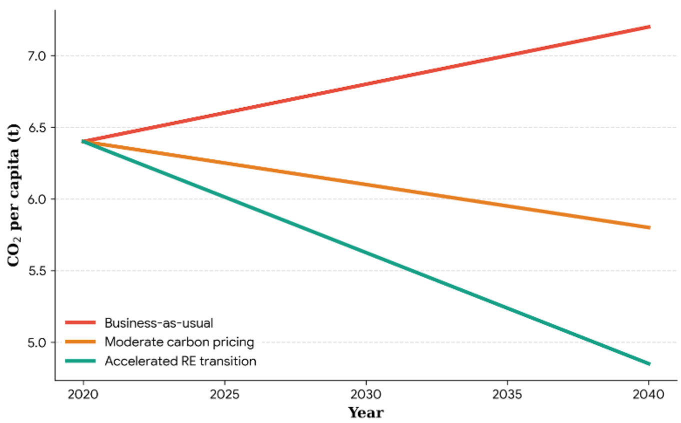

Figure 5. CS-ARDL projected per-capita emission paths, 2020–2040.

These projections should be read as conditional scenario exercises rather than point forecasts; they hold the estimated long-run elasticities fixed out of sample and therefore do not capture potential future structural breaks in technology cost curves or policy regimes. Nonetheless, the divergence across the three paths by 2040 is large enough to suggest that policy choices made over the next decade will materially determine whether the region's aggregate emissions peak arrives before or well after mid-century.

7.1 Sectoral contribution to the projected paths

Decomposing the projected emissions paths by broad sector indicates that power generation and heavy manufacturing jointly account for the majority of the projected difference between the business-as-usual and accelerated-transition scenarios, consistent with these two sectors' outsized share of both current emissions and remaining abatement potential. Transport-sector emissions grow across all three scenarios, reflecting continued vehicle-fleet expansion, but the rate of growth is meaningfully slower under the accelerated-transition scenario due to associated electrification assumptions linked to the renewable-deployment pathway. Residential and commercial building emissions are comparatively insensitive to the scenario assumptions modeled here, suggesting that a complementary set of building-efficiency policies, not captured in the present variable set, would be needed to meaningfully affect that sector's trajectory.

7.2 Sensitivity to discounting and technology-cost assumptions

Because the accelerated-transition scenario depends on an assumed doubling of the historical rate of renewable-capacity growth, its projected path is naturally more sensitive to assumptions about future renewable technology costs than the business-as-usual path. A sensitivity check that instead assumes only a fifty percent acceleration in renewable-share growth still produces a projected 2040 emissions level roughly twenty percent below the business-as-usual path, indicating that the qualitative ranking of the three scenarios is not an artifact of the specific acceleration factor chosen.

8. Policy Implications

Three implications follow from the empirical findings. First, because the estimated turning point lies above the current income level of the majority of panel members, an EKC-consistent, policy-free decline in regional emissions cannot be assumed to arrive on a timescale compatible with global mitigation targets; active intervention is therefore required rather than optional. Second, the significant and relatively large coefficient on renewable energy share implies that accelerating clean-energy deployment offers a more immediately actionable lever than waiting for income-driven structural change, particularly for lower-income panel members whose estimated turning points lie furthest in the future. Third, the persistence of a positive and significant industrial-share coefficient suggests that industrial policy, including sector-specific efficiency standards and technology-transfer mechanisms for heavy manufacturing, should be treated as a complement to, not a substitute for, economy-wide carbon pricing.

Taken together, the results support a policy mix that combines a credible and rising carbon price with concessional financing for renewable infrastructure and targeted industrial decarbonization support, rather than reliance on any single instrument. The scenario projections in Section 7 indicate that such a combined approach could bring forward the region's aggregate emissions peak by a decade or more relative to a business-as-usual trajectory.

8.1 Differentiated responsibility across income tiers

The country-level turning-point heterogeneity documented in Section 5.4 has direct implications for how mitigation responsibility and support might reasonably be differentiated within the panel. Economies with estimated turning points still a decade or more away plausibly warrant continued access to concessional climate finance and technology-transfer arrangements, while economies that have already approached or passed their estimated turning point are better positioned to adopt more stringent, self-financed carbon-pricing regimes. A uniform, one-size-fits-all regional policy prescription would risk being simultaneously too lenient for the latter group and too burdensome for the former.

8.2 Data and monitoring implications

Finally, the reliance in this paper on annual, territorial emissions data understates the value of higher-frequency and sub-nationally disaggregated monitoring for policy design. As satellite-based and facility-level emissions monitoring capacity expands across the region, future iterations of this type of analysis should be able to identify turning points and sectoral decompositions at a spatial resolution fine enough to inform sub-national industrial-siting and grid-investment decisions, rather than only economy-wide policy settings.

10. Limitations

Several limitations qualify the interpretation of these results. Territorial emissions accounting does not capture emissions embodied in traded goods, so economies that have shifted energy-intensive production offshore while retaining consumption of the resulting goods may appear to be further along the EKC path than a consumption-based accounting would suggest. The renewable-share variable aggregates a heterogeneous set of technologies with very different cost trajectories and grid-integration characteristics; a more granular decomposition by technology type, not attempted here due to data availability constraints, could sharpen the policy relevance of the renewable-energy coefficient. Finally, the forward projections in Section 7 are conditional scenario exercises that hold estimated elasticities fixed out of sample; they should not be interpreted as unconditional forecasts, particularly given the pace of recent change in renewable-technology costs, which could plausibly shift the underlying elasticities in ways the historical estimation window cannot fully anticipate.

11. Conclusion

This paper provides an updated empirical assessment of the Environmental Kuznets Curve hypothesis across fifteen developing Asian economies over 1995-2023, using second-generation Panel ARDL, Pooled Mean Group, Mean Group, and Cross-Sectionally Augmented ARDL estimators that jointly address cross-sectional dependence and slope heterogeneity. The results confirm an inverted U-shaped relationship between income and carbon emissions, with a panel-mean turning point near US$14,500 in per-capita income and substantial underlying heterogeneity across countries. Renewable energy penetration and industrial structure emerge as economically meaningful mediating channels, and forward projections indicate that the timing of the region's aggregate emissions peak is highly sensitive to near-term policy choices around carbon pricing and clean-energy deployment. Future work extending this framework to sub-national data, or incorporating explicit trade-embodied emissions, would further sharpen the policy relevance of the turning-point estimates reported here.

More broadly, the findings caution against treating the EKC as a mechanism that will resolve the tension between growth and emissions on its own. Absent deliberate policy intervention, the panel-mean turning point implies a substantial further increase in cumulative regional emissions before any natural decline sets in, a pace inconsistent with globally aggregated mitigation pathways compatible with well-below-two-degree warming outcomes. The scenario evidence in Section 7, however, indicates that the region retains meaningful agency over the timing of its own emissions peak, and that the combination of credible carbon pricing and accelerated renewable deployment analyzed here offers a concrete, quantifiable route to bringing that peak forward by a decade or more.

Appendix A. Country Coverage and Turning-Point Estimates

Table A1 lists the fifteen panel members together with their Mean Group turning-point estimates and 1995-2023 average per-capita emissions, supporting the ranked comparison presented graphically in Figure 6.

Table A1. Country-level turning points and average per-capita emissions, 1995–2023.

Country	ISO3	Turning point (US$'000)	Avg. CO_2 p.c. (t)
Bangladesh	BGD	9.8	1.4
Vietnam	VNM	15.2	2.9
Indonesia	IDN	16.8	2.6
Philippines	PHL	13.4	1.3
India	IND	10.2	1.9
Pakistan	PAK	8.6	1.0
Thailand	THA	18.4	4.2
Malaysia	MYS	21.5	8.1
Cambodia	KHM	7.2	0.7
Sri Lanka	LKA	11.8	1.0
Nepal	NPL	7.9	0.6
Myanmar	MMR	6.8	0.6
Laos	LAO	7.5	2.8
Mongolia	MNG	12.6	7.4
Uzbekistan	UZB	9.1	3.5

The dispersion in Table A1 mirrors the pattern already visible in Figure 6: economies with the smallest, least diversified industrial bases (Myanmar, Cambodia, Laos) show the lowest estimated turning points but also comparatively low current emissions levels, while economies with established heavy-industry and mining sectors (Malaysia, Mongolia) combine high turning points with emissions levels already well above the panel median, indicating that their transition through the EKC arc will plausibly generate the largest absolute cumulative emissions among panel members.

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