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Pollution and income: Looking into the environmental Kuznets curve in south Asian countries

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Abstract

This paper examines the validity of the environmental Kuznets curve (EKC) hypothesis in five south Asian countries —Bangladesh, India, Nepal, Pakistan and Sri Lanka over the period of 1981–2018. Employing second-generation panel data econometrics, it evaluates how income per capita and CO2 emissions are linked by taking into account the role of energy consumption and financial development. After applying appropriate testing procedures, the study employed the augmented mean group (AMG), the common correlated effects mean group (CCEMG) estimators and the heterogeneous panel causality tests suitable for cross-sectionally-dependent and heterogeneous panels. The EKC hypothesis is validated for India and Sri Lanka as an inverted U-shaped relation between economic growth and CO2 emissions is found. Heterogeneous panel causality tests confirm four bidirectional causal relationships (CO2 emissions and energy use, CO2 emissions and financial development, economic growth and energy use, and energy use and financial development) and two unidirectional causal relationships (CO2 emissions and economic growth, and financial development and economic growth). Validity of the EKC hypothesis essentially indicates that mostly energy-dependent economic growth can reduce environmental degradation in these countries. So, policy makers should look for alternatives to the traditional energy sources and try to expand renewable energy sources in order to reduce climate change and its impacts.

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1. Introduction

Kuznets (1955) hypothesized that income inequality rises with economic growth initially, but declines afterwards as economies grow over time. In that hypothesis, environment-related issues were absent. Later, especially in the 1990s, Kuznets' analysis was employed to study the link between environmental quality—*i.e.*, the evolution of pollution level—and economic growth. Accordingly, we end up with a curve that can best be described by an inverted U-shaped relationship, called the environmental Kuznets curve (EKC) (Grossman and Krueger, 1991 and 1995; Shafik and Bandyopadhyay, 1992; Holtz-Eakin and Selden, 1995). Intuitively, the EKC hypothesis suggests that although economic growth harms the environment in the initial days of development, it may benefit the environmental as economies grow further (Stern, 2004)[1].

There is already a vast literature aimed at examining the validity of the EKC hypothesis using the income–pollution linkage (Leal and Marques, 2022; Zhu et al., 2022; Kar, 2022; Sarkodie and Strezov, 2019b; Kaika and Zervas, 2013a, 2013b; Galeotti, 2007; Dinda, 2004). However, there is no consensus on the legitimacy of the EKC analysis as the obtained results are generally mixed. The relationship between economic growth and environmental quality cannot be clearly defined—it can be all between flat to N-shaped (Husnain et al., 2021). Panel studies on different country-clusters (*e.g.*, OECD, GCC, SAARC, CEE) have employed variables at aggregate level without focusing on individual country-level features (Kanli and Küçükefe, 2022), and found diversified results. The country-specific case studies have come up with varied findings too. Methodological differences apart, again, some regions and country-clusters have not even received proper research attention. For instance, Islam (2022), Józ´wik et al. (2022), Murshed et al. (2022), Khan et al. (2022), Ansari et al. (2020), Danish et al. (2018), Alam et al. (2015) and Chary and Bohra (2010) are some of the studies focused on south Asian countries. Differences in findings plus insufficient focus on certain regions justify the need for further studies.

This study consequently aims to meet the research need and focuses on five South Asian (SA) countries—namely Bangladesh, India, Nepal, Pakistan and Sri Lanka[2]—for the reasons described below. First, these countries are close neighbours to one another, have closer cultural, economic and political ties, and mostly similar in terms of their economic and financial development levels. Second, these member countries of SAARC (South Asian Association for Regional Cooperation) are highly dependent on fossil fuel-based energy sources. Third, they agreed to coordinate their environmental policies by following the United Nations Framework Convention on Climate Change (UNFCCC) embraced in the Paris Agreement (PA) for national and global mitigation action (Murshed et al., 2022; United Nations, 2016; and Latief et al. 2021). Fourth, India and Bangladesh in particular have experienced high economic growth in recent years, but severely challenged with energy supplies. With enormous growth potentials, these emerging energy-poor economies consume approximately one-third of the global primary energy (Danish et al., 2018; Alam et al., 2015). Besides, close to the shore of the Bay of Bengal, geo-political locations as well as economic worth of rising economies like India, Bangladesh and Sri Lanka are very significant.

[1] Recent studies of Kanli and Küçükefe (2022) and Husnain et al. (2021) provide a summary of the criticisms against the EKC theory.

[2] Sufficient observations on two other SAARC countries—Bhutan and Maldives—were not available at the time of data collection in September, 2023. For example, GDP per capita data for Maldives were only available for the period 1995-2018. Energy use data for Bhutan and Maldives were available with large gaps—only for the year 1990 and for the period 2004-2007. Hence, Bhutan and Maldives were not included in the analysis.

The study contributes to the existing literature in at least three ways. First, unlike previous studies, the study uses the second-generation panel econometric tests and methods. To be specific, tests were implemented for checking cross-sectional dependence (CSD), panel level heterogeneity, stationarity and cointegration patterns of the variables included in the analysis. Then, augmented mean group (AMG) and common correlated effects mean-group (CCEMG) estimators were employed to obtain consistent and efficient estimates. These estimators can take care of CSD appropriately also (Pesaran, 2006; Ali and Malik, 2021; Yang et al. 2022). Stationarity and cointegration analyses ensure long-run stable relationship among the variables. Thus, studies devoid of applying these techniques may result in biased results (detailed explanations are provided in section 2.3 entitled estimation procedures also). Second, unlike previous studies (*e.g.*, Murshed et al., 2022, Islam, 2022) the study is more policy-oriented as country-specific findings are presented. Third, to provide convincing empirical evidence, the study covers an expanded time period (1981-2018).

2. Materials and methods

2.1 Model specification

Several studies have examined the relationships between CO_2 emissions, energy consumption and economic growth using single equation models previously (see, for example, Shahbaz et al., 2012; Jalil and Mahmud, 2009; Ang, 2007; Soytas et al., 2007). Following this strand of literature, this paper describes environmental pollution as a function of real GDP, real GDP squared, energy consumption and financial development to investigate the validity of the EKC hypothesis in selected South Asian countries[3]. The empirical model in panel data format can be written as follows:

$$\ln CO_{2it} = \beta_0 + \beta_1 \ln Y_{it} + \beta_2 \ln Y_{it}^2 + \beta_3 \ln EC_{it} + \beta_4 \ln FD_{it} + \mu_{it} \qquad (1)$$

where countries are denoted by the subscript i (i = 1, 2…5), the subscript t denotes the time period (t = 1, 2…, 38) and the term 'ln' stands for natural logarithm. A log-linear specification provides more efficient estimates (Cameron, 1994). CO_2 refers to carbon-dioxide (a greenhouse gas) emissions of which is used as a proxy for environmental degradation, Y stands for gross domestic product (GDP) per capita to indicate income, Y^2 is the squared term of Y used to check the existence of the EKC and μ is a stochastic error term. Thus, checking the validity of the EKC hypothesis is basically to examine whether economic growth is coming at the cost of environmental degradation. Following the studies of Frankel and Romer (1999), Birdsall and Wheeler (1993) and Frankel and Rose (2005), this paper also includes measures of energy consumption (EC) and financial development (FD) as other explanatory variables. These variables have been included in the model as they are linked with human activities and can affect the CO_2 concentrations in the environment directly or indirectly. Above and beyond, consumption of non-renewable (renewable) energy may increase (decrease) environmental degradation (Baek, 2015; Destek and Sarkodie, 2019).

2.2 Data

This study employs annual data on CO_2 emissions per capita, GDP per capita, energy consumption and financial development for the abovementioned South Asian countries over the period 1981–2018. The data were sourced from the World Development Indicators (WDI) and the Financial Structure Database of the World Bank[4]. The selection of time span has been

[3] Many studies have also included a cubic term of Y (*i.e.*, Y^3) to check whether the EKC curve is N-shaped.
[4] Data are available at http://data.worldbank.org

largely dictated by data availability as observations on all variables and years were not available. The number of total observations was 190. But 20 observations (10.53%) were missing for both the CO_2 emissions and energy consumption variables (data from 1981-2014 were only available), whereas 12 observations (6.32%) were missing for the financial development variable. Except for Bangladesh, financial development data from 1981-2017 were available for all other countries; for Bangladesh, FD data from 1986-1992 and for 2018 were unavailable. However, complete 190 observations were available for the GDP and GDP-squared variables. As data of these variables and years were unavailable at the source database (*i.e.*, the World Bank databank), the reason of such random missingness is basically unknown. Thus, the dataset is an unbalanced panel of 5 countries followed over 38 years. Among the variables, per capita CO_2 emissions (measured in metric ton), real GDP per capita (measured in 2010 U.S. dollar) and energy consumption (measured in kg of oil equivalent per capita) have been collected from the WDI database. While, data on financial development (measured by "private credit by deposit money banks and other financial institutions percent of GDP") were sourced from the Financial Structure Database. The variables have been transformed into natural logarithm. Thus, the estimates represent the elasticities of the explained variable in terms of the explanatory variables. Table 1 describes the variables used in the analysis with respective data sources, whereas Table 2 summarizes the descriptive statistics.

2.3 Estimation procedures

Employing panel data is advantageous in empirical estimations. A panel dataset has more observations, which clearly allow for variations in both time-series and cross-section dimensions of the data. However, it is typically plagued with cross-sectional dependence (CSD) and slope heterogeneity problems (Baltagi et al., 2005) that can lead to spurious, biased and inconsistent estimates if conventional panel unit root tests and procedures are applied in estimations (Apergis et al., 2022). Therefore, to overcome those issues, the current study implements the second-generation panel data modelling. The procedure involves a few tests implemented in steps, each of which produces findings to be used as the basis for the next step. To start with, CSD of the panels is checked. This test is conducted under the null hypothesis of cross-section independence [CSD ~ N (0,1)] and p-values close to zero indicate that the data are correlated across panel groups. Then, checking for slope heterogeneity is important. This test is conducted under the null hypothesis of "slope coefficients are homogenous" and rejection of the null hypothesis confirms that the slopes are indeed heterogeneous. Next, depending on whether the panels are cross-sectionally dependent or not, appropriate unit root tests are used. Accordingly, CIPS and CADF panel unit root tests were used[5]. The CIPS test statistic is achieved from the mean of the t-statistics in the panel series (*i.e.*, the CADF values for individual cross-sections). The null hypothesis assumes the existence of non-stationarity in data. We can reject the null hypothesis—and follow the stationary property at their first difference—if the CIPS value exceeds the critical threshold value. The presence of unit root then requires applying proper cointegration tests to confirm if any long-run cointegrating relationship exists among the variables included in the analysis. Subsequently, the study applies Pedroni (2004), Kao (1999) and Westerlund (2005) cointegration tests in the next step. The null hypothesis of "no cointegration" is rejected for p-values close to zero in Pedroni and Kao tests. For checking robustness of cointegration results above, the Westerlund test is used. A low p-value (less than 0.05) for the variance ratio rejects the null hypothesis of no co-integration at 95% confidence level. Then in the next step appropriate estimation models are chosen to estimate the long-run parameters. This study subsequently addresses the estimation

[5] CIPS stands for cross-sectional Im, Pesaran, and Shin (2003) and CADF means cross-sectional Augmented Dickey Fuller tests.

challenges by employing the augmented mean group (AMG) estimator (Eberhardt and Teal, 2010) and the common correlated effects mean group (CCEMG) estimator (Pesaran, 2006). Pesaran (2006) shows that consistent estimates of the regression (slope) coefficients can be obtained by the CCEMG panel data estimators without the need to determine the number of unobserved common factors, given the regressors are stationary and exogenous. Consistency of the estimators is robust to non-stationarity or common factors as well (Pesaran, 2006). The AMG and CCEMG perform equally well in terms of bias or root mean squared error in panels with nonstationary variables (cointegrated or not) and multifactor error terms (cross-section dependence) (Eberhardt and Bond 2009). Besides, the AMG estimator takes care of the CSD and country-specific heterogeneity, which is one of the major advantages of using this estimator. Assessing the causal links, if any, among the variables is required for offering better policy suggestions. Consequently, the last step is about using an appropriate panel causality test to check the directions of causality and the presence of any feedback effect. This study uses the Dumitrescu and Hurlin (2012) test for Granger causality in panel data. In this test, the null hypothesis of a panel variable's not Granger-causing another panel variable is rejected for p-values close to zero.

3. Results

The study performed the cross-sectional dependence (CSD) test (to check the CSD in the dynamic panels for the residuals) and country-level slope homogeneity test in the first stage of analysis. Findings of Table 3 confirm CSD among the selected countries as the null hypothesis of cross-sectional independence is rejected for all tests. This intuitively suggests that a shock may spill-over to other countries if it occurs in any of the selected countries. The homogeneity test results presented in Table 4 confirm country-specific slope heterogeneity as the null hypothesis of homogeneous coefficients is rejected. In the next step, CADF and CIPS unit root tests were employed. The results of these tests in Table 5 confirm that though most variables are non-stationary at level, they become stationary at their first differenced form. Then, having recognized that all variables follow unit root processes, the study employs the cointegration tests of Pedroni (2004), Kao (1999) and Westerlund (2005). According to the results of Table 6, all the cointegration tests reject the null hypothesis of no cointegration among the variables.

In the next step, the study employs the AMG and CCEMG estimators to investigate the effects of economic growth (measured by real GDP per capita), squared values of economic growth, energy consumption and financial development on CO_2 emissions[6]. The estimation results presented in Table 7 confirm that the coefficients of real GDP per capita variable are positive and statistically significant only in India (either at 10% or at 5% levels in AMG and CCEMG estimations) and Sri Lanka (at 5% level only in CCEMG estimation). Likewise, the coefficients of the quadratic term are negative and statistically significant at 5% level in these countries. In terms of magnitudes, the estimates of the elasticity parameters suggest that a 1% rise in real GDP per capita is associated with a 3.34%-36.40% increase in CO_2 emissions in the initial days of economic growth on average, all else equal. However, other things being equal, the marginal impact of economic growth leads to a reduction in CO_2 emissions by 0.29%-2.59% beyond a certain level. Thus, the results confirm the validity of the EKC hypothesis for India and Sri Lanka suggesting the existence of an inverted U-shaped relationship between per capita income and environmental degradation. The AMG model in panel regressions confirm the validity of the EKC hypothesis as well, which further confirms an inverted U-shaped association between

[6] In regressions, the dependent variable (CO_2 emissions, measured in metric tons per capita), with much lower mean values, is regressed on a set of regressors with high mean values. This plausibly explains why we have obtained high-valued regression coefficients.

environmental degradation and economic growth in the context of selected South Asian countries if they are considered as a single country. These findings are consistent with those of, for example, Murshed and Dao (2022), Rahman (2017) and Zhang et al. (2017). One plausible explanation to these results is that environmental awareness increases as income levels rise in these countries. Better environmental awareness may act as a driving force that enables people to demand for clean environment, which results in binding environmental policies, regulations and laws for reducing pollution. These arguments go hand in hand with those of Sarkodie and Strezov (2019a). As claimed by Sarkodie (2018), again, decline in environmental pollution may also be attributed to technological advancement and structural changes in economic growth. The coefficients of energy use variable are highly significant in all countries excepting Nepal. This clearly suggests that an increase in energy consumption leads to an increase in environmental degradation in these countries. Concerning the nexus between energy use and environmental degradation, two separate hypotheses—one of which supports a positive link while another supports a negative link—have been developed in the literature. The results of this study are in agreement with the hypothesis that supports the positive linkage. In this connection, for instance, Sarkodie and Adams (2018) note that while clean and renewable energy technologies promote a clean environment, fossil fuel energy technologies increase environmental pollution. Thus, the positive and highly significant coefficients of the energy use variable confirm that increased use of fossil fuel simply adds to high level of CO_2 emissions in the selected south Asian countries. In case of Nepal, however, this study finds no significant relationship between energy use and CO_2 emissions. Plausibly, this can be Nepal's insignificant use of fossil fuels in comparison with its neighbouring countries like India and China.

Again, the coefficients of the financial development variable are negative and statistically significant only in Pakistan (AMG model) and Sri Lanka (CCEMG model). Both positive and negative linkages between financial development and environmental degradation have both been discussed in the literature. The positive significant coefficient indicates that environmental degradation increases with financial sector development. Similar results have been found in earlier studies (Zhang, 2011; Boutabba, 2014; Khan et al., 2018; Shahbaz et al., 2016; Bekhet et al., 2017; Al-Mulali et al., 2015). This result essentially supports the hypothesis that financial development leads to higher emission rates. Otherwise, the coefficients of this variable for AMG estimations of other countries and in CCEMG models all along are statistically insignificant.

In the final step, causal relationships among CO_2 emissions, economic growth, energy consumption, and financial development have been examined using the heterogeneous panel causality tests proposed by Dumitrescu and Hurlin (2012). The results are shown in Table 8, which provide four bidirectional ($lnCO_2 \leftrightarrow lnEUS$, $lnCO_2 \leftrightarrow lnFD$, $lnGDP \leftrightarrow lnEUS$ and $lnEUS \leftrightarrow lnFD$) and two unidirectional ($lnCO_2 \rightarrow lnGDP$ and $lnFD \rightarrow lnGDP$) causalities. Essentially, a bidirectional causality between two variables suggests a feedback effect. Thus, the results of this exercise show that CO_2 emissions homogeneously cause both energy use and financial development. Similarly, economic growth causes and is caused by energy use and energy use causes and is caused by financial development. For instance, a bidirectional causality between financial development and energy use suggests that financial development causes consumption of energy and the other way around (Islam, 2022). The feedback hypothesis also suggests that the rate of natural resource depletion and environmental stress will ultimately decline if production and consumption of natural resources can be managed sustainably (Destek and Sarkodie, 2019). A bidirectional causality between economic growth and energy use—as found in Islam (2022) as well—similarly suggests that increased per capita

GDP homogeneously causes energy use to increase and vice versa. Similar explanations are applicable to other bidirectionally causal links.

A unidirectional causality running from CO_2 emissions to economic growth means that CO_2 emissions homogeneously cause economic growth, but not vice versa. This is a situation where sustainable management options have been integrated into the production and consumption process. So, the rate of natural resource depletion and environmental stress is declined that allows resources to regenerate (Destek and Sarkodie, 2019; United Nations, 2016). The unidirectional causality running from CO_2 emissions to economic growth also means that increased CO_2 emissions from fossil fuel-based industries and transportation results in economic growth (possibly environmentally unfriendly) in this region. But the opposite is not true since economic growth may not always cause CO_2 emissions. Similarly, the unidirectional causality running from financial development to GDP per capita tells us about respective one-way causations. That is, no feedback effect is in place, and financial development homogeneously and positively causes economic growth, but not vice versa. Actually, financial development helps to diversify risk, enables financing at low-cost and promotes income and wealth generation by way of boosting business confidence. Thus, financial development is helpful for any country to grow economically (Acheampong 2019; Sadorsky 2010). Financial development, in turn, increases purchasing power of consumers and makes low-cost capital available, which motivates firms and governments to invest in industrial projects and to develop physical infrastructure (Tamazian et al. 2009; Tamazian and Rao 2010).

4. Discussion and conclusions

This paper inspects the validity of the EKC hypothesis in five South Asian countries over the period of 1981–2018. This region serves as a useful case study for other countries and provide valuable lessons on the dynamics and processes required for achieving low-carbon energy transitions. Employing second-generation panel data econometric techniques, the study aims to evaluate how economic growth and CO_2 emissions are linked by taking the role of energy consumption and financial development into account. First, the CSD test as well as slope homogeneity test have been performed. Then employing the AMG and CCEMG estimators suitable for cross-sectionally-dependent and heterogeneous panels, the study validates the EKC hypothesis for India and Sri Lanka only as it found an inverted U-shaped relationship between economic growth and CO_2 emissions in these countries. For other countries, no clear trend is observed. Heterogeneous panel causality tests used in the study confirm four bidirectionally ($lnCO_2 \leftrightarrow lnEUS$, $lnCO_2 \leftrightarrow lnFD$, $lnGDP \leftrightarrow lnEUS$ and $lnEUS \leftrightarrow lnFD$) and two unidirectionally ($lnCO_2 \rightarrow lnGDP$ and $lnFD \rightarrow lnGDP$) causal relationships.

Validity of the EKC hypothesis confirmed in this study essentially indicates that environmental degradation can be reduced via economic growth. This also means that economic growth in India and Sri Lanka is energy-dependent to a large extent. Hence, dependence on traditional sources of energy like fossil fuel, coal etc. should be reduced in the long run and policy makers should look for alternatives to the traditional energy sources. In other words, it is essential for the policy makers to try to expand renewable energy sources in order to reduce climate change and its impacts. These sources include, but not limited to, solar, wind, biofuel and geothermal energy. Future research should investigate the relationship between economic growth and environmental degradation possibly by considering other possible shapes (including the cubic term), different functional forms and capturing other dimensions (*e.g.*, corruption, governance and trade openness) that help define the differences between countries.

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Appendix

Table 1. Variable descriptions and sources of data

Variable name	Description	Data source
Dependent variable		
CO_2 emissions	CO_2 emissions (Metric tons per capita)	World Development Indicators
Independent variable		
GDP per capita	Gross Domestic Product (Constant 2010 US$)	World Development Indicators
Energy use	KG of oil equivalent per capita	World Development Indicators
Financial development	Private credit by deposit money banks and other financial institutions percent of GDP	Financial Structure Database

Notes: World Development Indicators (WDI) and Financial Structure Database are compiled by the World Bank.

Table 2. Descriptive statistics

Country		CO_2 emis.	GDP p.c.	GDP p.c. sq.	Energy use	Fin. Dev.
Bangladesh	N	34	38	38	34	30
	Mean	-1.573	6.339	40.301	4.976	2.988
	SD	0.489	0.357	4.603	0.240	0.611
	Min	-2.347	5.923	35.083	4.653	1.583
	Max	-0.747	7.093	50.307	5.435	3.707
India	N	34	38	38	34	37
	Mean	-0.123	6.754	45.835	6.008	3.380
	SD	0.370	0.475	6.481	0.223	0.341
	Min	-0.747	6.082	36.994	5.683	2.958
	Max	0.547	7.650	58.524	6.456	3.908
Nepal	N	34	38	38	34	37
	Mean	-2.442	6.121	37.553	5.806	3.090
	SD	0.644	0.300	3.697	0.100	0.710
	Min	-3.568	5.655	31.982	5.709	2.000
	Max	-1.209	6.706	44.973	6.074	4.300
Pakistan	N	34	38	38	34	37
	Mean	-0.366	6.734	45.382	6.047	2.925
	SD	0.230	0.191	2.569	0.121	0.159
	Min	-0.852	6.363	40.491	5.796	2.693
	Max	-0.055	7.088	50.244	6.215	3.300
Sri Lanka	N	34	38	38	34	37
	Mean	-0.892	7.505	56.527	5.956	2.965
	SD	0.461	0.454	6.872	0.190	0.402
	Min	-1.591	6.852	46.957	5.713	1.943
	Max	-0.122	8.278	68.526	6.312	3.785
Total	N	170	190	190	170	178
	Mean	-1.079	6.690	45.120	5.759	3.073
	SD	0.960	0.599	8.249	0.440	0.503
	Min	-3.568	5.655	31.982	4.653	1.583
	Max	0.544	8.278	68.526	6.456	4.300

Source: Author’s own calculations from the data collected from the WDI database.

Table 3. Pre-estimation test on cross-section dependence (CD-Test)

Variable	CD-test	p-value	Av. Joint T	Mean ρ	Mean abs(ρ)
CO2 emissions	17.007	0.000	34.00	0.92	0.92
GDP p.c.	19.16	0.000	38.00	0.98	0.98
GDP p.c. squared	19.157	0.000	38.00	0.98	0.98
Energy use	16.536	0.000	34.00	0.90	0.90
Fin. Development	10.062	0.000	34.20	0.55	0.55

Notes: CD presents the Pesaran (2021) cross-section dependence statistic under the null hypothesis of cross-section independence, CD ~ N(0,1). The average and absolute correlation coefficients have been reported. P-values close to zero indicate data are correlated across panel groups. The Stata routine 'xtcdf' has been used.

Table 4. Pesaran and Yamagata (2008) slope homogeneity (*i.e.*, PY 2008) and Blomquist and Westerlund (2013) slope heterogeneity (*i.e.*, BW 2013) test results

Statistic (for homogeneity)	PY 2008 Test		BW 2013 Test	
	Value	P-value	Value	P-value
Delta-tilde ($\tilde{\Delta}$)	-2.030	0.042	-2.010	0.044
Delta-tilde adjusted ($\widetilde{\Delta_{AdJ.}}$)	2.449	0.014	-2.273	0.023

Note: Null hypothesis of the tests was "slope coefficients are homogenous". Small p-values confirm rejection of the null hypothesis. Balanced panels have been used in both tests.

Table 5. CIPS (Cross-sectional IPS) and CADF (Cross-sectional ADF) panel unit root test results

Variables	CIPS Tests		CADF Tests	
	CIPS	CV (1%)	Z[t-bar]	P-Value
Case 1: level form				
Deterministics chosen (models with): constant only				
Carbon dioxide (CO_2) emissions	-1.333	-2.41	1.617	0.947
GDP per capita	-2.093	-2.41	-0.349	0.364
GDP per capita squared	-1.998	-2.41	-0.195	0.423
Energy use	-1.191	-2.41	1.853	0.968
Financial development	-1.959	-2.41	-1.853	0.032
Deterministics chosen (models with): constant and trend				
Carbon dioxide (CO_2) emissions	-2.282	-3.15	0.495	0.690
GDP per capita	-2.052	-3.15	1.035	0.850
GDP per capita squared	-1.985	-3.15	1.160	0.877
Energy use	-1.901	-3.15	0.646	0.741
Financial development	-1.853	-3.15	-1.231	0.109
Case 2: first difference				
Deterministics chosen (models with): constant only				
Carbon dioxide (CO_2) emissions	-5.882	-2.36	-4.347	0.000
GDP per capita	-4.777	-2.36	-5.361	0.000
GDP per capita squared	-4.718	-2.36	-5.115	0.000
Energy use	-5.245	-2.36	-3.506	0.000
Financial development	-3.340	-2.41	-3.075	0.001
Deterministics chosen (models with): constant and trend				
Carbon dioxide (CO_2) emissions	-6.069	-3.00	-3.791	0.000
GDP per capita	-5.204	-3.15	-5.367	0.000
GDP per capita squared	-5.115	-3.15	-5.063	0.000
Energy use	-5.834	-3.00	-2.995	0.001
Financial development	-3.480	-3.15	-2.333	0.010

Note: IPS means Im, Pesaran, and Shin (2003) and ADF means Augmented Dickey Fuller tests. All variables are in natural logarithm (except inflation). H_0: Contains a unit root.

Table 6. Results of panel cointegration tests

Pedroni test

	Statistic	P-value
Modified Phillips–Perron t	-0.2539	0.3998
Phillips–Perron t	-3.0263	0.0012
Augmented Dickey–Fuller t	-3.3555	0.0004

Kao test

	Statistic	P-value
Modified Dickey–Fuller t	-2.8936	0.0019
Dickey–Fuller t	-2.2990	0.0108
Augmented Dickey–Fuller t	-2.1977	0.0140
Unadjusted modified Dickey–Fuller t	-3.8756	0.0001
Unadjusted Dickey–Fuller t	-2.6023	0.0046

Westerlund test

	Statistic	P-value
Variance ratio	-1.6919	0.0453

Note: H_0: No cointegration, Ha: All panels are cointegrated.

Table 7. AMG and CCEMG estimation results

	Model	GDP	GDP^2	Energy use	Fin. Dev.	Constant
Bangladesh	AMG	7.568	-0.594	1.746***	0.099	-34.639*
		(4.193)	(0.305)	(0.335)	(0.077)	(14.253)
	CCE	-11.024	0.918	1.665***	0.046	-65.131*
		(12.947)	(1.023)	(0.334)	(0.110)	(26.312)
India	AMG	3.339*	-0.278**	1.964***	-0.061	-21.754***
		(1.388)	(0.095)	(0.170)	(0.068)	(5.658)
	CCE	8.939**	-0.707**	1.454***	-0.041	-21.355**
		(3.144)	(0.234)	(0.212)	(0.063)	(6.994)
Nepal	AMG	8.149	-0.450	-0.482	0.011	-32.431
		(8.497)	(0.669)	(1.015)	(0.191)	(31.208)
	CCE	-20.963	1.877	-0.527	-0.097	12.647
		(24.250)	(2.006)	(1.084)	(0.183)	(43.054)
Pakistan	AMG	4.549	-0.315	0.962***	0.074*	-22.818**
		(2.519)	(0.187)	(0.157)	(0.032)	(7.855)
	CCE	9.465	-0.682	0.737**	0.088	-48.884**
		(5.786)	(0.447)	(0.280)	(0.053)	(17.822)
Sri Lanka	AMG	2.096	-0.105	1.992***	0.011	-22.273
		(5.718)	(0.330)	(0.423)	(0.080)	(23.696)
	CCE	36.403**	-2.586**	1.552***	0.236*	105.242**
		(12.139)	(0.837)	(0.387)	(0.116)	(32.950)
Panel	AMG	5.129***	-0.348***	1.731***	0.027	-22.282***
		(1.291)	(0.092)	(0.292)	(0.030)	(26.812)
	CCE	4.294	-0.229	1.411***	0.042	-12.553
		(10.588)	(0.821)	(0.251)	(0.065)	(34.323)

Note: All variables have been transformed into natural logs. Each group-specific regression has been augmented with a linear 'trend' term. These terms were statistically significantly in all country-specific individual regressions. Asterisks (*, ** and ***) indicate statistical significance at 10%, 5% and 1% levels respectively. Numbers in parentheses are the robust standard errors. Coefficient averages computed as outlier-robust means (using 'rreg')

Table 8. Heterogeneous panel Granger causality test (Dumitrescu and Hurlin, 2012) results

	Wald Stat.	P-value	Decision
$lnCO_2 \nRightarrow lnGDP$	2.745**	0.006	$lnCO_2 \rightarrow lnGDP$
$lnGDP \nRightarrow lnCO_2$	1.878	0.165	
$lnCO_2 \nRightarrow lnEUS$	3.668***	0.000	$lnCO_2 \leftrightarrow lnEUS$
$lnEUS \nRightarrow lnCO_2$	3.392***	0.000	
$lnCO_2 \nRightarrow lnFD$	2.804**	0.004	$lnCO_2 \leftrightarrow lnFD$
$lnFD \nRightarrow lnCO_2$	6.2443***	0.000	
$lnGDP \nRightarrow lnEUS$	36.327***	0.000	$lnGDP \leftrightarrow lnEUS$
$lnEUS \nRightarrow lnGDP$	3.381***	0.000	
$lnGDP \nRightarrow lnFD$	1.470	0.457	$lnFD \rightarrow lnGDP$
$lnFD \nRightarrow lnGDP$	10.048***	0.000	
$lnEUS \nRightarrow lnFD$	2.562	0.014	$lnEUS \leftrightarrow lnFD$
$lnFD \nRightarrow lnEUS$	4.714**	0.002	

Note: *, ** and *** indicates statistical significance at 10, 5 and 1% level, respectively. Symbol $\nRightarrow$ indicates "does not homogeneously cause", whereas symbols $\leftrightarrow$ and $\rightarrow$ respectively indicate bidirectional and unidirectional causality. P-values correspond to Z-bar p-values obtained by using Stata's 'xtgcause' routine. In order to determine how many lags to use, this study uses the Schwarz' Bayesian Information Criterion (BIC). The number of lags is determined using the minimum BIC value. Interpolation technique has been used to fill-in the missing values as Stata's 'xtgcause' routine requires strongly balanced dataset without gaps.