Investigating the agriculture-induced environmental Kuznets curve hypothesis in South Asian economies

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Abstract

Purpose – The main purpose of this study is to investigate the agriculture-induced environmental Kuznets curve (EKC) hypothesis in South Asian economies (SAE).

Design/methodology/approach – This study employs econometric techniques, including Westerlund cointegration tests, cross-sectional augmented distributive lag model (CS-ARDL) and Dumitrescu and Hurlin (DH) causality tests to investigate the relationship between renewable and non-renewable energy consumption, agriculture, economic growth, financial development and carbon emissions in SAE from 1990 to 2019.

Findings – The CS-ARDL test outcome supports the presence of the agriculture-induced EKC hypothesis in SAE. Additionally, through the application of the DH causality test, the study confirms a unidirectional causality running from renewable energy consumption (REC), fossil fuel consumption (FFC), economic growth (GDP), and squared economic growth (GDP^2) to carbon dioxide (CO2) emissions.

Research limitations/implications – This study proposes that future research should extend comparisons to worldwide intergovernmental bodies, use advanced econometric methodologies for accurate estimates, and investigate incorporating the service or primary sector into the EKC. Such multidimensional studies can inform various methods for mitigating global climate change and ensuring ecological sustainability.

Originality/value – Environmental degradation has been extensively studied in different regions and countries, but SAE face significant constraints in addressing this issue, and comprehensive studies in this area are scarce. This research is pioneering as it is the first study to investigate the applicability of the agriculture-induced EKC in the South Asian region. By filling this gap in the current literature, the study provides valuable insights into major SAE and their environmental challenges.

Keywords Renewable energy, Carbon emissions, Agriculture-induced EKC, South Asia

Paper type Research paper

1. Introduction

In light of the Sustainable Development Goals, sustainable economic growth, low-carbon economies, energy transition, climate-smart agriculture and green technology have become enormously imperative themes in the agenda of academic scholars, environmental economists, statistical organizations and policymakers (Pirgaip et al., 2023; Yahya and Lee, 2023). The 27th Conference of the Parties (COP27) summit in 2022 brought together several parties to discuss the Paris Agreement and the United Nations (UN) climate change framework. Several goals have been set under COP27, including reducing global warming, providing financial support to developing countries so they can address climate issues, minimizing dependency on fossil fuels and establishing emergency policies to address environmental threats (Zarkik, 2022). In addition, it is proposed to reduce greenhouse gas (GHG) emissions by more than seven Giga tonnes by 2030, in order to restore the ecosystem and manage the sustainability of land (Liu et al., 2022a, b). The rapid expansion of pollution over recent years has resulted in global environmental threats. This contamination is mainly caused by carbon dioxide (CO2) and has increased from 3.80 to 4.50 tons (Mt) per capita between 1995 and 2019 (World Bank, 2022).
According to the World Bank (2022), environmental degradation is a critical factor that hampers socioeconomic progress worldwide, with South Asia no exception. Recent climate model projections suggest that the temperature in South Asia is poised to rise by several degrees Celsius by the end of the century, and the Himalayas may experience a temperature increase of up to 6 °C under high GHG concentration scenarios (Almazroui et al., 2020). Moreover, the Intergovernmental Panel on Climate Change (IPCC) predicts an increase in the average temperature of 0.88–3.16 °C by 2050 and 1.56–5.44 °C by 2080 in South Asia (Kaur et al., 2017). In terms of worldwide CO2 emissions, India accounts for approximately 7.09%, while Pakistan and Bangladesh contribute 0.5 and 0.21% of CO2 emissions, respectively (Pandey and Asif, 2022). Under these circumstances, environmental protection has become an important concern to ensure the region’s green economy and environmental sustainability.

Despite this, these countries have aggressive emission-reduction targets, putting them at the forefront of the fight against climate change. India has committed to lowering its CO2 emission intensity by 45% by 2030 compared to 2005 levels, while Pakistan and Sri Lanka aim for 50 and 14.5% reductions by the same year (Mercer-Blackman et al., 2023). Meanwhile, Bangladesh has announced that it will reduce its emissions reduction target by 2030 from 12 Metric tons of carbon dioxide equivalent (MtCO2e) to 27.56 MtCO2e compared to business as usual (UNDP, 2023). Although these economies are striving to reduce their CO2 emissions, their agricultural sector, which is a major contributor to environmental degradation, may hinder their efforts. The Food and Agriculture Organization (Food and Agriculture Organization of the United Nations (FAO), 2016) has reported that the agricultural industry is accountable for 21% of global CO2 emissions, and it is anticipated to rank as the second largest emitter in the upcoming years. This sector is responsible for soil degradation and deforestation, in addition to releasing methane and nitrous oxide. Land use, deforestation and agriculture contribute up to one-quarter of GHG emissions (Balogh, 2022). Despite these activities being carried out for economic growth and development, the increase in these activities is strongly associated with the deprivation of the environment, particularly the rapidly increasing levels of GHGs, primarily carbon dioxide. The study (Holly, 2015) revealed that methane and nitrous oxide from soil management and livestock are some of the major causes of CO2 emissions in agricultural production. Further study (Beheshti Tabar et al., 2010) showed that the increase in agricultural production results in greater consumption of fossil fuels, poor water quality and deforestation. The agricultural sector relies heavily on non-renewable energy for irrigation purposes, such as diesel and oil. Fertilizers rich in nitrogen are also used by farmers to maintain their yields, but this practice adds to GHG emissions. Usman and Makhdum (2021) introduce a fresh agricultural production approach centred on value addition, which may enhance farmer profitability and job security. Nevertheless, the implementation of this approach may have negative effects on biodiversity. However, Liu et al. (2017) have reported that the agricultural sector can make a noteworthy contribution towards reducing global GHG emissions by 20–60% by 2030 by curbing deforestation rates and generating renewable energy. Therefore, South Asian nations are in a prime position to play a vital role in mitigating emissions related to agriculture.

South Asia’s efforts to achieve sustainable development are intensifying as a result of the area’s high susceptibility to climate change. The livelihood of about 70% of the population in South Asian economies (SAE) depends on agriculture, which is exacerbated by global warming and climate change, posing a risk to economic growth as well (Aryal et al., 2020). Despite the ongoing discussion, the shape of the environmental Kuznets curve (EKC) theorem plays an essential and prolific role in explaining the dynamic linkage between economic activities, ecological balance and environmental sustainability in various countries around the world. It is widely acknowledged by researchers that the utilization of cleaner energy sources, such as renewables and nuclear power, would result in comparatively lower detrimental effects on the environment. The problem of environmental degradation has been
2. A review of the literature

In this section, we will discuss the findings of previous empirical studies, which fall into four study strands. First, there is a literature strand that investigates the relationship between economic growth and the degradation of the environment. Several hypotheses regarding the association between CO₂ emissions and economic growth have been proposed in the previous literature, including the one-way causality hypothesis, the bi-directional hypothesis and the neutrality hypothesis. Given this context, numerous studies have sought, with mixed results, to establish the relationship between environmental degradation and economic growth. For example, Ali et al. (2023) and Vo and Ho (2021) have demonstrated the presence of a bidirectional causal relationship between economic growth and the deterioration of the environment. In a study of BRICS economies, Li et al. (2022) found a unidirectional association between environmental pollution and economic growth from 2000 to 2019. Regmi and Rehman (2021) come to a similar conclusion, and other research suggests that there is no causal relationship between economic growth and environmental pollution. Eyuboglu and Uzar (2022), Guoyan et al. (2022), De Pascale et al. (2020) report that between 2000 and 2017, 36 OECD nations showed some short-run support for the EKC hypothesis but some variation over the long run. According to Churchill et al. (2018), the panel model applied to 20 OECD countries from 1870 to 2014 revealed significant country-level variations. However, the EKC hypothesis is supported by a substantial majority of empirical studies (Khezri et al., 2022). The model’s specification variables, econometric techniques, studied nations and time periods and other factors all affect the outcomes, though.

The second line of earlier research centres on the nexus between environmental degradation and the consumption of renewable energy. Understanding how CO₂ affects renewable energy is crucial because it has been determined that renewable energy will be critical in the future of sustainable energy. Due to these factors, there have been many studies conducted in this area, but no consensus has been reached. CO₂ emissions have risen dramatically as a result of increased reliance on non-renewable energy sources. In response to this, policymakers are urged to move away from conventional energy sources in favour of renewable ones (Assi et al., 2021; Shaheen et al., 2020; Zafar et al., 2019) make the argument that when countries employ outdated production technologies, their energy consumption
negatively impacts the quality of the environment. A multitude of studies conducted across various nations has revealed that the utilization of fossil fuels results in an increase in CO₂ emissions (Selvanathan et al., 2023). Several studies have provided evidence of a link between the use of renewable energy and a decrease in environmental degradation (Assi et al., 2021; Sampene et al., 2022; Selvanathan et al., 2023; Wang et al., 2023). According to Khezri et al. (2022), the use of renewable energy has a long-term negative association with CO₂ emissions. Additionally, Pata and Samour (2022) found that renewable energy consumption significantly reduced GHG emissions in ASEAN countries. Lu (2018) and Yu et al. (2023) highlight that the utilization of renewable energy is limited by inherent constraints related to natural resources, such as the availability of land and sufficient sunlight for the deployment of photovoltaic (PV) modules to harness solar energy. Similarly, Park et al. (2018) observe that numerous European Union countries are utilizing renewable energy sources such as geothermal, wave and wind power due to their availability and accessibility. They recommend a mix of energies in order to reduce the use of non-renewable energy sources. The consumption of green energy and emissions of CO₂ have been shown to have a bi-directional relationship in many studies (Dogan and Seker, 2016).

The third strand of the existing research investigating the dynamic linkage between agricultural production and CO₂ emissions is limited, mainly in South Asian countries. The scant literature on various nations and regions yields mixed results, with justifications for both negative and positive relationships. The study by Aluwani (2023) and Selvanathan et al. (2023) showed that agricultural production enhances CO₂ emissions by using more energy for heating, cooling and using more raw materials on land as well as chemicals, fertilizers and pesticides. Specifically, Stolze et al. (2000) mentioned that organic farming minimizes the adverse effects of agriculture on the environment by reducing the use of pesticides and harmful fertilizers. Further evidence for a positive correlation between CO₂ emissions and agriculture production has been presented by Sampene et al. (2022) in SAE and Shah et al. (2022) in BRICS countries. Selvanathan et al. (2023) noted that agriculture, on the other hand, helps to increase the production of oxygen in the atmosphere, which improves the environmental quality and ecological balance. This result and outcome have been corroborated by Rafiq et al. (2016), Jebli and Youssef (2017), Liu et al. (2017).

The fourth strand of the existing literature pertains to the examination of the relationship between non-renewable energy consumption and carbon emissions. Previous studies conducted by Destek and Sinha (2020) and Selvanathan et al. (2023), have established that the primary cause of the increase in CO₂ emissions is the utilization of non-renewable energy. This finding has been widely acknowledged and accepted. Soytas et al. (2007) employed the Granger causality procedure to test for long-term causality and revealed that fossil fuel energy consumption leads to CO₂ emissions in the United States. Shafiei and Salim (2014) used the stochastic impacts by regression on technology, population and affluence model to investigate the determinants of CO₂ emissions, using OECD data from 1980 to 2011, and revealed that fossil fuel energy consumption leads to CO₂ emissions. Various studies conducted in different countries over the years have found similar results. Erdogan et al. (2020) found similar results in 24 OECD countries, Dogan and Ozturk (2017) in the United States, Ahmad et al. (2022) in India, Selvanathan et al. (2023) in 24 OECD countries, Sampene et al. (2022) in South Asian countries, Liu (2021) in China and Ibrahim and Ajide (2021) in G7 countries.

3. Data and methods
3.1 Model specification
In this study, we investigate the impact of agricultural value added, GDP per capita, renewable energy consumption, fossil fuel consumption and financial development on CO₂
emissions in four SAE – Bangladesh, India, Pakistan and Sri Lanka – through the analysis of panel data spanning the period from 1990 to 2020. We did not include Afghanistan, Bhutan, Nepal and Maldives because the data were not available. A detailed description of the variables can be found in Table I. The fundamental model used for the study is shown in equation (1):

\[
CO_{2it} = f \left( REC, FFC, GDP, GDP^2, AGRI, FD \right)
\]

where \( CO_2 \) refers to carbon dioxide emission, \( REN \) denotes renewable energy consumption, \( FF \) represents fossil fuel per capita, \( GDP \) denotes gross domestic product per capita, \( GDP^2 \) denotes the square of GDP, \( AGRI \) denotes the agriculture value-added and \( FD \) denotes financial development. To overcome the problem of heteroscedasticity and outliers, all the variables are transformed into logarithm form. The econometric presentation of equation (1) is specified below:

\[
CO_{2it} = \theta_0 + \theta_1 REC_{it} + \theta_2 FFC_{it} + \theta_3 GDP_{it} + \theta_4 GDP^2_{it} + \theta_5 AGRI_{it} + \theta_6 FD_{it} + \epsilon_{it}
\]

where \( \theta_0, \theta_1, \theta_2, \theta_3, \theta_4, \theta_5 \) and \( \theta_6 \) are coefficients and \( \epsilon_{it} \) is the residual term. To account for the nonlinear relationship between \( CO_2 \) emissions and agricultural production, as revealed by empirical studies, we modify equation (2) as follows:

\[
CO_{2it} = \delta_0 + \delta_1 REC_{it} + \delta_2 GDP_{it} + \delta_3 GDP^2_{it} + \delta_4 AGRI_{it} + \delta_5 AGRI^2_{it} + \delta_6 FD_{it} + \mu_{it}
\]

where \( AGRI^2 \) is the square of agriculture value-added, \( \delta_0, \delta_1, \delta_2, \delta_3, \delta_4, \delta_5 \) and \( \delta_6 \) are the coefficients and \( \mu_{it} \) is the error term.

### 3.2 Methodology

#### 3.2.1 Cross-sectional dependence tests

The examination of cross-section dependence holds significant importance in empirical studies involving panel data, especially in cases where representative nations share comparable economic characteristics, such as emerging nations, advancing economies and transitioning countries. When economies exhibit similarities, they become susceptible to the effects of external shocks from other nations, attributed to factors like international trade, financial integration and globalization. Consequently, the analysis of cross-sectional dependency becomes a crucial aspect of empirical research employing panel data (Destek and Sarkodie, 2019; Breusch and Pagan, 1980). Our study employed four tests (Breusch and Pagan, 1980; Pesaran CD; Pesaran Scaled Lagrange Multiplier and Baltagi; Feng and Kao bias-corrected scaled LM) to detect cross-sectional dependence. Using the

<table>
<thead>
<tr>
<th>Variables</th>
<th>Description</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO2</td>
<td>CO2 emissions per capita</td>
<td>Our World in Data Database</td>
</tr>
<tr>
<td>REC</td>
<td>Renewable Energy consumption (% of total final energy consumption)</td>
<td>WDI</td>
</tr>
<tr>
<td>FFC</td>
<td>Fossil fuel consumption per capita</td>
<td>Our World in Data Database</td>
</tr>
<tr>
<td>GDP</td>
<td>Gross domestic product per capita (constant 2015 US$)</td>
<td>WDI</td>
</tr>
<tr>
<td>AGRI</td>
<td>Agriculture value added (% of GDP)</td>
<td>WDI</td>
</tr>
<tr>
<td>FD</td>
<td>Domestic credit to private sector by banks (% of GDP)</td>
<td>WDI</td>
</tr>
</tbody>
</table>

Table 1. Data description
Pesaran and Yamagata (2008) test, we analyse whether the slope coefficient is homogeneous or heterogeneous based on the dispersion of the weighted slopes.

3.2.2 Panel unit root test. After examining the cross-sectional dependence, the next step is to assess the stationarity of the variables. Keeping into account cross-sectional dependence and heterogeneity, the study employed two novel second-generation panel unit root tests, namely the “cross-sectionally augmented Dickey–Fuller (CADF) and the cross-sectionally augmented Im-Pesaran-Shin (CIPS) tests”. These advanced tests are intended to account for cross-sectional dependence and heterogeneity, offering more robust and accurate assessments of whether a variable exhibits a unit root in panel data sets. By considering these factors, second-generation panel unit root tests offer improved reliability in detecting stationary or non-stationary behaviour across the panel, making them a preferred choice in empirical research. The mathematical representation of the CADF test is presented below.

\[ \Delta y_{i,t} = \pi_i + \rho_i y_{i,t-1} + \tau_i y_{i,t-1} + \sum_{l=0}^{b} \tau_{il} \Delta y_{i,t-l} + \sum_{l=1}^{b} \rho_{il} \Delta y_{i,t-l} + \epsilon_{it} \]  

whereas \( y_{i,t} \) represents the variables employed in the study, \( \Delta \) denotes the difference operator, where \( y_{i,t-1} \) and \( \Delta y_{i,t-1} \) denote the cross-sectional averages of lagged levels and first differences, respectively, at time \( T \) for all cross-sectional units and \( \epsilon_{it} \) denotes the usual white noise term. The mathematical version of the CIPS test is represented by the following equation:

\[ CIPS = \frac{1}{N} \sum_{i=1}^{N} CADF_i \]

3.2.3 Westerlund cointegration test. The next stage of the analysis involves conducting cointegration tests on non-stationary variables. This step serves two primary purposes. Firstly, it aims to validate the estimation of the long-term equilibrium (cointegrating) equation. Secondly, it provides a means to assess the results of Granger non-causality testing. One of the main limitations of the earlier cointegration tests (e.g. Pedroni, Koa) is that it relies on cross-sectional independence, which may lead to unreliable and spurious results. To overcome this issue, we employed the Westerlund test, which assumes cross-sectional dependence. Equation (6) illustrates the representation of the Westerlund and Edgerton (2007) test.

\[ \Delta y_{i,t} = \pi' d_i + \theta_i (y_{i,t-j} - \delta x_{i,t-1}) + \sum_{j=1}^{b_j} \theta_{ij} \Delta y_{i,t-j} + \sum_{j=0}^{b_j} \varphi_{ij} \Delta x_{i,t-1} + \epsilon_{it} \]  

Westerlund introduced four statistics: \( G_\alpha, G_\tau, P_\alpha \) and \( P_\tau \). The \( G_\tau \) and \( G_\alpha \) statistics are utilised to identify cointegration in individual or multiple cross-sectional units. Meanwhile, the \( P_\tau \) and \( P_\alpha \) statistics are employed to identify cointegration across the entire panel.

3.2.4 Cross-section augmented distributed lags (CS-ARDL). This study employed the cross-section augment autoregressive distributed lags (CS-ARDL) approach developed by Chudik and Pesaran (2015), which is a modern econometric methodology used to estimate short-term and long-term results. The CS-ARDL approach is considered to be more efficient and reliable than alternative approaches such as AMG, FMOLS, DOLS, CCEMG and PMG. While AMG and CCEMG assume cross-sectional dependence, they fall short in providing short-run estimates. On the other hand, PMG, FMOLS and DOLS do not incorporate cross-sectional dependence into the model. One of the primary reasons for using the CS-ARDL approach is its ability to overcome endogeneity and heterogeneous slope coefficients and produce reliable results despite cross-sectional dependence issues. The econometric formulation of the CS-ARDL is depicted below:
\[ y_{i,t} = \alpha_i + \sum_{j=1}^{p} \varphi_{ij}y_{i,t-j} + \sum_{j=0}^{p} \delta_{ij}x_{i,t-j} + \sum_{j=0}^{p} \pi_{ij}z_{i,t-j} + \epsilon_{it} \]  (7)

where \( z_{i,t-j} = (\bar{y}_{i,t-j}, \bar{x}_{i,t-j}) \) denotes averages of all lagged cross-sectional variables. The mean group estimates of the long-run coefficient are represented by the equation below:

\[
\hat{\theta}_{CS-ARDL} = \frac{\sum_{i=0}^{p} \delta_{il}}{1 - \sum_{i=1}^{p} \varphi_{il}}
\]  (8)

\[
\hat{\theta}_{MG} = \frac{I}{N} \sum_{i=1}^{N} \hat{\theta}_{i}
\]  (9)

where \( \hat{\theta}_{i} \) represents individual estimations of each cross-sectional unit. In the same vein, the equation below illustrates the error correction structure of the CS-ARDL method:

\[
\Delta y_{i,t} = \varnothing (y_{i,t-j} - \hat{\theta}_{i}x_{i,t}) - \alpha_i + \sum_{j=1}^{p} \Delta \varphi_{ij}y_{i,t-j} + \sum_{j=0}^{p} \delta_{ij}\Delta x_{i,t-j} + \sum_{j=0}^{p} \pi_{ij}z_{i,t-j} + \epsilon_{it}
\]  (10)

where \( \varnothing \) denotes error correction speed of adjustment.

3.2.5 Dumitrescu and Hurlin panel causality test (DH). Finally, the Dumitrescu and Hurlin (2012) Granger causality test is employed in the present research study to analyse the directional flow and causal associations between variables. The current causality test takes into account the heterogeneity of causal associations as well as the heterogeneity of the econometric regression model utilized to test causality (Dumitrescu and Hurlin, 2012). The econometric representation of the DH test is presented below:

\[
y_{i,t} = \vartheta_i + \sum_{z=1}^{Z} \varphi_i(z)y_{i,t-z} + \sum_{z=0}^{Z} \beta_i(z)x_{i,t-z} + \epsilon_{it}
\]  (13)

where \( \vartheta_i \) is individual fixed effects, \( \varphi_i \) and \( \beta_i \) denotes the lag estimators and slope estimators, respectively, \( k \) denotes lag length. In this test, the null hypothesis posits that the panel econometric model lacks any causal association, whereas the alternative hypothesis proposes that there is a causal association in at least one cross-sectional unit.

4. Results and discussion

A few preliminary statistics of the variables have been conducted before conducting a long-run estimation. As a result, the first test carried out on the dataset is descriptive statistics. This test explains how data is structured. Table 2 summarizes the data from 1990 to 2019. The standard deviations for most variables are lesser than the means, demonstrating that the model’s variables have not been subject to outliers or significant variations.

Testing for slope heterogeneity (Table 3) has uncovered that the model is afflicted with heterogeneity, which leads to biased outcomes in conventional unit-root tests and cointegration. Table 4 displays the results of several tests, including the Scaled LM test, Breusch–Pagan LM test, bias-corrected scaled LM test and Pesaran CD cross-sectional tests, performed on the variables being investigated. The results of CADF and CIPS unit roots tests are depicted in Table 5. According to the estimated outcomes of the CIPS test; the provided
series are of order one integration and stationery at the first difference. The CADF test results differ slightly, but they do not affect our general conclusions.

Table 6 display the outcomes of the Westerlund cointegration test. The estimated results from the second-generation cointegration test developed by Westerlund verify the long-run equilibrium relationship among variables.

Based on the preliminary tests, Table 7 presents the results for the cross-section ARDL estimation. The CS-ARDL test found that in South Asian countries, there is an inverted U-shaped relationship between GDP per capita and CO₂ emissions, supporting the EKC theory. This means that as GDP per capita increases, CO₂ emissions initially increase but start to decrease at higher levels. These outcomes suggest that the rate of CO₂ emissions grows as GDP per capita increases up to 2.87 units (in log), after which it commences to decrease. As a result of our evaluation, we are able to support the EKC theorem in both models for SAE. This is being catalysed by the use of cleaner energy solutions in production processes, which are replacing fossil fuel-based energy sources. Further, as incomes rise, citizens' education and environmental awareness also rise, and this catalyses cross-border diffusion of cleaner technologies via public–private partnerships. Thus, economic growth

### Table 2.
Descriptive statistics

<table>
<thead>
<tr>
<th></th>
<th>CO₂</th>
<th>REC</th>
<th>FFC</th>
<th>GDP</th>
<th>GDP²</th>
<th>AGRI</th>
<th>AGRI²</th>
<th>FD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>-0.232</td>
<td>1.700</td>
<td>3.397</td>
<td>3.079</td>
<td>0.991</td>
<td>1.272</td>
<td>1.642</td>
<td>1.440</td>
</tr>
<tr>
<td>Median</td>
<td>-0.177</td>
<td>1.712</td>
<td>3.440</td>
<td>3.071</td>
<td>0.307</td>
<td>1.334</td>
<td>1.781</td>
<td>1.441</td>
</tr>
<tr>
<td>Minimum</td>
<td>-0.881</td>
<td>1.393</td>
<td>2.813</td>
<td>2.709</td>
<td>0.333</td>
<td>0.870</td>
<td>0.758</td>
<td>0.944</td>
</tr>
<tr>
<td>Maximum</td>
<td>0.278</td>
<td>1.882</td>
<td>3.795</td>
<td>3.626</td>
<td>5.769</td>
<td>1.500</td>
<td>2.252</td>
<td>1.719</td>
</tr>
<tr>
<td>Std. dev.</td>
<td>0.274</td>
<td>0.104</td>
<td>0.225</td>
<td>0.227</td>
<td>1.358</td>
<td>0.150</td>
<td>0.356</td>
<td>0.174</td>
</tr>
</tbody>
</table>

Source(s): Authors’ own creation

### Table 3.
Results of slope heterogeneity

<table>
<thead>
<tr>
<th></th>
<th>Model I</th>
<th></th>
<th>Model II</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Test</td>
<td>Value</td>
<td>p-value</td>
<td>Value</td>
<td>p-value</td>
</tr>
<tr>
<td>Δ</td>
<td>5.890</td>
<td>0.000*</td>
<td>8.119</td>
<td>0.000*</td>
</tr>
<tr>
<td>Δ Adjusted</td>
<td>6.877</td>
<td>0.000*</td>
<td>9.481</td>
<td>0.000*</td>
</tr>
</tbody>
</table>

Note(s): *is for a 1% statistical significance level

Source(s): Authors’ own creation

### Table 4.
Cross sectional dependences test results

<table>
<thead>
<tr>
<th>Variables</th>
<th>Breusch–Pagan LM test</th>
<th>Scaled LM test</th>
<th>Bias-corrected Scaled LM test</th>
<th>Pesaran CD test</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>156.9376*</td>
<td>43.51792*</td>
<td>43.50296*</td>
<td>12.52*</td>
</tr>
<tr>
<td>REC</td>
<td>153.3793*</td>
<td>42.54475*</td>
<td>42.47578*</td>
<td>12.38*</td>
</tr>
<tr>
<td>FFC</td>
<td>163.4806*</td>
<td>45.46072*</td>
<td>45.39175*</td>
<td>12.78*</td>
</tr>
<tr>
<td>GDP</td>
<td>175.7438*</td>
<td>49.00082*</td>
<td>48.93185*</td>
<td>13.26*</td>
</tr>
<tr>
<td>GDP²</td>
<td>93.05033*</td>
<td>25.12927*</td>
<td>25.06030*</td>
<td>1.73***</td>
</tr>
<tr>
<td>AGRI</td>
<td>87.99209*</td>
<td>23.66908*</td>
<td>23.60011*</td>
<td>8.36*</td>
</tr>
<tr>
<td>AGRI²</td>
<td>88.7005*</td>
<td>23.87358*</td>
<td>23.80461*</td>
<td>8.33*</td>
</tr>
<tr>
<td>FD</td>
<td>84.27079*</td>
<td>22.59483*</td>
<td>22.52586*</td>
<td>1.65***</td>
</tr>
</tbody>
</table>

Note(s): * and ***are for 1 and 10% statistical significance levels

Source(s): Authors own creation
patterns in these nations indicate progress towards SDG achievement. This finding is consistent with previous research carried out by Selvanathan et al. (2023), Zakaria and Bibi (2019), and Khezri et al. (2022).

Our primary objective, however, is to explore the agriculture-induced environmental Kuznets curve hypothesis, which can be seen in model 1 from the positive correlation between agricultural GDP and CO₂ emission in both the short period and long period. Based on the estimated result, agriculture in South Asian countries increases CO₂ emissions. Deforestation and resource extraction at a rate that exceeds regeneration is another reason for agricultural EKC. Additionally, rapid industrialization increases toxic compounds and non-degradable waste (Sinha et al., 2017) that threaten to undermine the UN’s sustainable development goals 12 (i.e. responsible production and consumption) and 13 (i.e. climate action). There is an intuition that agriculture value added and CO₂ are positively correlated because farmers in the South Asian regions do not use renewable energy sources or innovative technology in their agricultural activities, contributing to high CO₂ levels. These findings are consistent with those of Shah et al. (2022), Sampene et al. (2022), Zhang et al. (2019) and Dogan (2019). The results derived from Model 2 indicate a significant U-shaped association between CO₂ emissions and agricultural value added. The results show that as the agriculture value added increases, CO₂ emissions initially decrease until they reach a turning point of 1.36 units (in log). After this turning point, CO₂ emissions start to increase again. The present study has identified a non-linear correlation between CO₂ emissions and agricultural value added in SAE, which has not been documented previously in the existing literature under the framework of the EKC.

Regarding renewable energy consumption (REC), both short-term and long-term results show that renewable energy reduces CO₂ emissions negatively and statistically significant.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Level</th>
<th>CIPS</th>
<th>Ist difference</th>
<th>Level</th>
<th>CADF</th>
<th>Ist difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>-1.556</td>
<td>-4.610*</td>
<td>-1.555</td>
<td>-3.186*</td>
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<td></td>
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<tr>
<td>REC</td>
<td>-1.280</td>
<td>-4.756*</td>
<td>-1.079</td>
<td>-2.625**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FFC</td>
<td>-2.137</td>
<td>-5.094*</td>
<td>-1.702</td>
<td>-3.415*</td>
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<td></td>
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<tr>
<td>GDP</td>
<td>-1.524</td>
<td>-3.883*</td>
<td>-1.237</td>
<td>-2.915*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GDP²</td>
<td>-2.062</td>
<td>-3.121*</td>
<td>-3.405*</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AGRI</td>
<td>-1.164</td>
<td>-5.137*</td>
<td>-1.311</td>
<td>-3.203*</td>
<td></td>
<td></td>
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<tr>
<td>AGRI²</td>
<td>-1.321</td>
<td>-5.195*</td>
<td>-1.380</td>
<td>-3.344***</td>
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<td></td>
</tr>
<tr>
<td>FD</td>
<td>-1.941</td>
<td>-4.644*</td>
<td>-2.204</td>
<td>-2.523***</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Note(s): *, ** and *** are for 1, 5 and 10% statistical significance levels*

**Source(s):** Authors’ own creation

Table 5. Results of panel unit root tests

Table 6. Results of Westerlund panel cointegration test
Given *a priori* assumptions, it is obvious that using renewable energy will lead to less pollution and, consequently, less carbon dioxide emissions (Ren et al., 2020). The results are not surprising considering the amount of investment South Asian countries have made in renewable energy. Aside from being pollution-free, renewable forms of energy can serve as an effective countermeasure to environmental risks and threats to energy security (Dogan et al., 2021). Furthermore, renewable energy has the added benefit of decreasing CO₂ emissions, emitting only 0.02 to 0.04 pounds of CO₂ E/kWh. In comparison, non-renewable sources such as coal combustion emit 1.4 to 3.6 pounds of CO₂ E/kWh (Shah et al., 2022). This finding is consistent with studies conducted by Pata and Samour (2022) and Guoyan et al. (2022).

Regarding the effect of fossil fuels consumption (FFC) on CO₂ emissions, our research findings illustrate a direct and positive relationship between fossil fuels and CO₂ emissions. These results align with the research of Ahmad et al. (2022) on India and (Selvanathan et al., 2023) on OECD countries.

In addition, model 1 finds that financial development (FD) is significantly and positively correlated with carbon emissions. However, this linkage is significantly observed both in the short and long run. This means that more financial development in SAE is causing more carbon emissions. Shahzad et al. (2017) also provide research findings that confirm financial development’s significant positive influence on carbon emissions in the economy of Pakistan. The same is true for Zhang (2011), who confirms that FD is a major contributor to carbon emissions in China’s economy. Our findings indicate that by offering loans to boost the economy in Asia’s developing regions, the financial sector produces scale effects. Because financial development is unrestricted and unplanned in developing regions, energy-efficient and environment-friendly projects are not being targeted, resulting in negative effects on the

<table>
<thead>
<tr>
<th>Variables</th>
<th>Model 1</th>
<th>p-value</th>
<th>Model 2</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co2</td>
<td>-0.651</td>
<td>0.000*</td>
<td>-0.880</td>
<td>0.000*</td>
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<tr>
<td>REC</td>
<td>0.549</td>
<td>0.071***</td>
<td>-</td>
<td>-</td>
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<tr>
<td>FFC</td>
<td>1.768</td>
<td>0.000*</td>
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<td>0.000*</td>
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<tr>
<td>GDP</td>
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<td>0.041**</td>
<td>-0.159</td>
<td>0.069**</td>
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<tr>
<td>GDP²</td>
<td>0.159</td>
<td>0.017**</td>
<td>-2.564</td>
<td>0.047**</td>
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<tr>
<td>AGRI</td>
<td></td>
<td></td>
<td>0.935</td>
<td>0.078***</td>
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<tr>
<td>AGRI²</td>
<td>0.114</td>
<td>0.072***</td>
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<td>FD</td>
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<td>0.000*</td>
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<table>
<thead>
<tr>
<th>Turning point</th>
<th>Extreme point</th>
<th>Lower bound</th>
<th>Upper bound</th>
<th>Structure</th>
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<tr>
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<td>3.6261</td>
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</tr>
<tr>
<td>Agricultural</td>
<td>1.3698</td>
<td>0.8708</td>
<td>1.5007</td>
<td>U-shaped</td>
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</tbody>
</table>

Note(s): * and ** and *** represent 1, 5 and 10% statistical significance levels, respectively.

Source(s): Authors’ own creation
environment. Low institutional quality is one of the reasons why Asia’s developing economies suffer from negative environmental consequences of financial development.

As a final note, the results of Models 1 and 2 indicate that the adjustment term is negative and significant at a significance level of 1% and that the adjusted terms are around 83% in Model 1 and 87% in Model 2, indicating an annual correction of 83 and 87% of disequilibrium, respectively.

4.1 Causality test results
D-H non-causality results are summarized in Table 8. The findings revealed a one-way causality running from renewable energy consumption, FFC, GDP and GDP² to CO₂. In these economies, it seems that implementing policies aimed at fostering economic growth beyond a certain threshold level and adopting renewable energy sources can effectively decrease CO₂ emissions. Moreover, there is evidence to suggest that there is a unidirectional causal relationship from CO₂ to AGRI and AGRI². Furthermore, the estimated results of the D-H causality test reveal the bidirectional relationship between FD and CO₂. Any policy aimed at both FD and CO₂ can thus, reduce carbon emissions in South Asian countries at the same time.

5. Conclusion and policy recommendations
Agricultural growth accounts for approximately 20% of total global CO₂ emissions, making it the second most significant contributor to climate change via CO₂ emissions, nitrous oxide and methane (Balsalobre-Lorente et al., 2019). In this regard, the current study examined the effects of economic growth, agriculture value added, consumption of renewable energy, financial development and FFC on CO₂ emissions in a few South Asian nations between 1990 and 2019. The significance of agriculture in South Asian nations, along with the fact that this sector is the second-largest emitter of greenhouse gases globally (Shah et al., 2022), highlights the need for us to focus our research on agriculture-induced EKC in SAE. We use CSD, Westerlund cointegration tests, CS-ARDL tests, and Dumitrescu–Hurlin Causality tests in order to examine the agriculture-induced EKC in South Asian countries.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>REC ≠ CO₂</td>
<td>2.5948</td>
<td>2.2554</td>
<td>0.0241**</td>
<td>REC → CO₂</td>
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<tr>
<td>CO₂ ≠ REC</td>
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<td>0.4869</td>
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<tr>
<td>FFC ≠ CO₂</td>
<td>3.1154</td>
<td>2.9917</td>
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<tr>
<td>CO₂ ≠ FFC</td>
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<td>0.1009</td>
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<td>3.3347</td>
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<td>-0.7302</td>
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<td>CO₂ ≠ GDP²</td>
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<td>GDP² → CO₂</td>
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<td>CO₂ ≠ AGRI²</td>
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<td>AGRI² ≠ CO₂</td>
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<tr>
<td>FD ≠ CO₂</td>
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<td>FD → CO₂</td>
</tr>
<tr>
<td>CO₂ ≠ FD</td>
<td>2.3444</td>
<td>1.9012</td>
<td>0.0573***</td>
<td>CO₂ → FD</td>
</tr>
</tbody>
</table>

Table 8.

Note(s): *, ** and *** are for 1, 5 and 10% statistical significance levels; the symbols ≠ (does not homogeneously cause) and → (Unidirectional)
Source(s): Authors’ own creation
The CS-ARDL test’s estimated results suggest that per capita GDP has a positive effect, while per capita GDP square has a negative effect on CO₂ emissions. Our findings further revealed a positive relationship between FFC, financial development, agricultural production and CO₂ emissions. Therefore, the current study proves the existence of agricultural-induced EKC in selected South Asian countries. A negative impact of renewable energy consumption on CO₂ emissions was also found during the study period. Furthermore, agricultural production has a negative influence on CO₂ emissions, while the square of agricultural production has a substantial positive influence on CO₂, respectively. In light of this, we found strong evidence of a non-linear relationship between CO₂ emission and agricultural production. Based on the causality analysis, CO₂ emissions and financial development have a bidirectional causal relationship. Moreover, we found that CO₂ emissions are caused unidirectionally by renewable energy consumption, non-renewable consumption, GDP and GDP². Moreover, there is a one-way causality association running from CO₂ to AGRI and AGR².

Using the empirical findings of the present study as an underpinning, this study proposed the policy framework for improving environmental quality and sustainability. Reducing the use of fossil fuels is a primary need for South Asian nations to achieve Sustainable Development Goal 7 (SDG-7) of affordable and clean energy, and this step is critical for reducing CO₂ emissions. By improving energy efficiency, agriculture can reduce its contribution to CO₂ emissions without compromising its production capacity. In light of this, South Asian countries should develop policies based on the latest technologies in clean energy production, industrial development and electricity generation. In order to achieve SDG-12 (responsible consumption and production), it is essential to focus on these policy areas. Along with technological advancements, South Asian countries would need a substantial amount of funding and grants to minimise the cost of generating and consuming renewable energy.

Furthermore, SAE should use renewable energy more and improve the equipment and machinery they use to feed their crops, all of which contribute to achieving SDG 13 on climate action. Aside from encouraging relevant institutions and experts in the energy sector, South Asian countries should promote the development of economically friendly renewable energy products. To support the development of new renewable energy sources, policymakers should implement appropriate policies and measures to promote the steady and sustainable use of renewable energy sources. To attain SDG 11 of sustainable cities and communities, South Asian countries need to expand the deployment of renewable energy sources.

Regenerative agricultural techniques, like no-till techniques, should also be supported and encouraged in order to boost soil fertility and tackle climate change. As no-till agriculture requires the least destruction to the soil, it is often associated with regenerative agriculture since it is capable of restoring additional carbon. As a result of using this method, soil erosion can also be reduced and CO₂ emissions can be reduced.

There are a few limitations to this study. The current study focuses on selected South Asian countries. As a result, future studies can compare the benefits of renewable energy in South Asian countries to other intergovernmental groups such as the G20, BRICS or emerging nations. Furthermore, advanced econometric techniques can be used to obtain reliable estimates in this area. Last but not least, we focused on enhancing the EKC through the integration of agricultural production. However, upcoming researchers could explore the potential of incorporating the service sector or primary sector into EKC to deepen our understanding. Conducting multidimensional analyses in this manner would facilitate the examination of diverse approaches to achieving global climate change mitigation and ecological sustainability.
References


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