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Greening Agriculture: Exploring the Asymmetric Impact of Agriculture on Carbon Emissions in SCO Countries

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Abstract: The emission of CO_2 becomes a main reason for environmental damage. Among various sources, this study aims to focus on the impact of agriculture on CO_2 emissions. While agriculture plays a vital role in supplying essential foods, it also contributes to ecological ruin. Using the Nonlinear Panel Autoregressive Distributed Lag (NPARDL) model, the study investigates the nonlinear impacts of agriculture on CO_2 emissions in Shanghai Cooperation Organization (SCO) nations for the period of 1992–2020. The results indicate that negative shocks to agriculture lead to substantial CO_2 emission reductions, in both the short- and long run, whereas shocks that are positive do not show a statistically significant short-run effect but result in statistically significant increase in emissions in the long-run. The study highlights the importance of sustainable agricultural practices and renewable energy consumption in mitigating carbon emissions. By linking these findings to the principles of Green Economics, this research emphasizes the need for policies that balance agricultural productivity with environmental conservation, promoting eco-friendly farming techniques and efficient resource use. The results provide actionable insights for policymakers in SCO countries to achieve sustainable development goals while addressing climate change challenges.

Keywords: Green Economics, carbon emissions, agriculture, SCO countries, sustainable development, NPARDL model.

Introduction

The foundation of our economic advancement along with being a substantial cause behind environmental destruction emerges from agricultural operations that generate carbon emissions. Agriculture comes under growing global climate change assessment because it serves both economic growth functions and produces greenhouse gas emissions. The agricultural sector remains crucial because it provides food security and supports livelihoods, in particular, throughout developing and emerging economies. The agricultural sector simultaneously puts severe stress on ecosystems through forest destruction together with land transformation and by releasing carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) which act as powerful greenhouse gases (GHGs) that fuel global warming (Lynch et al., 2021). It is vital to grasp this dual aspect because it helps solve the current climate crisis without sacrificing agricultural productivity.

The Shanghai Cooperation Organization member states consisting of China Russia and India Pakistan and multiple Central Asian nations represent a special environment to study agricultural effects on carbon emissions. Research into atmospheric CO2 rise is extensive because human activities spanning deforestation and agriculture proved to be key contributors (Rahman & Velayutham, 2020). FAO (2020) indicates that agriculture has caused increasing damage to the climate between 2010 and 2014 as CO2 emissions from agriculture grew from 5575 Mt to 5800 metric tons. The research investigates how agricultural activities contribute to environmental deterioration while showing that agricultural practices generate unequal carbon emissions patterns.

The Shanghai Cooperation Organization (SCO) plays a pivotal role in global demographics, economics, and environmental policy. Comprising nearly 42% of the world's population (Britannica, 2024) and contributing about 23% to the global GDP (Vision IAS, 2024), SCO countries are critical for addressing pressing issues like climate change. Among these nations, China, India, and Russia rank as the first, third, and fourth largest carbon emitters, respectively (IEA, 2023; Reuters, 2023). Despite this, limited research explores the sectoral dynamics within these countries, particularly the complex interplay between agriculture—a cornerstone of their economies and carbon emissions.

The member states encompass economies at different development levels where agriculture dominates the economic framework. China along with Russia demonstrates extensive industrialized agriculture yet their farming operations generate noticeable CO_2 releases but the land management practices in Uzbekistan and Tajikistan remain unindustrialized causing environmental damage due to overgrazing alongside poor water resource management (Jiang et al., 2023). The SCO region serves perfectly as a study environment because its diverse agricultural practices enable researchers to observe carbon emission interactions. Figure 1 provides a map of the SCO countries, highlighting their geographical distribution.

Figure 1: Geographical location of SCO members. Source: Visualcapitalist.com

The research uses Green Economics as a valuable framework to study sustainable development through economic policy integration of environmental elements. According to Green Economics (Kennet & Heinemann, 2006) practitioners should implement practices that combine an improved environment with sustainable economic development. Agricultural transitioning must occur toward sustainable farming while reducing both fossil fuel consumption and implementing efficient resource utilization practices. The research implements

Green Economics methods to analyze how farming practices within SCO member states can achieve sustainability objectives.

Studies of carbon emissions continue to increase yet researchers lack a complete comprehension of how asymmetrical agricultural impacts on CO_2 emissions affect the SCO region. Most research analyzing this relationship has established linear operations while ignoring the possibility that positive and negative agricultural changes affect environmental pollution differently. The study fills this knowledge gap through the NPARDL modeling approach to evaluate asymmetries between short- and long-term relationships between agricultural activities and carbon emissions. The study enhances Green Economics knowledge through examination of farming policy strategy effectiveness in supporting both economic development and ecological preservation.

Literature Review

Academic research has thoroughly investigated agriculture's role in producing carbon emissions, but researchers have not thoroughly studied the uneven impact that farming practices create in CO_2 emissions. Research shows that agricultural activities produce 24% of total greenhouse gas emissions by causing deforestation as well as the degradation of soil and the application of chemical fertilizers (IPCC, 2021). Agriculture supports our food security needs and drives economic development yet generates substantial adverse effects on the environment. Green Economics serves as a vital conceptual framework to understand the dual nature of this topic since it aligns sustainability with development along with environmental policy integration (Kennet & Heinemann, 2006). (Choudhury, T et al. 2023) found that energy consumption and GDP have a positive association with corban emissions in both the short and long run.

The research shows sustainable agricultural methods have become essential to reduce carbon emissions in the environment. According to Lynch et al. (2021) agriculture differs from other industries regarding climate change effects because natural resource dependency exists and carbon-sequestration abilities are possible. The researchers endorse policies to implement sustainable farming techniques including organic farming, agroforestry and precision agriculture because these techniques decrease emissions yet maintain productivity levels. Research by Rehman et al. (2022) demonstrates that environmentally friendly agricultural technologies result in substantial cuts to CO_2 emissions mainly within developing nations.

Researchers have extensively discussed how renewable energy assists in reducing agricultural emissions. Akram et al. (2020) established that rising agricultural renewable energy consumption generates significant carbon emission decreases. The authors applied their research to BRICS countries to understand how renewable energy implements two beneficial outcomes: environmental protection and sustainable agricultural productivity enhancement through dependable renewable power supply. Kennet and Heinemann (2006) identify the green economic principle of renewable energy transition as an essential method to develop sustainable development.

Several factors influence the agricultural-carbon emission relationship within SCO nations because these member states show varying economic and environmental traits. Two countries that lead the world in agricultural output namely China and India have grown their carbon emission rates due to excessive farming methods combined with fossil fuel consumption (Jiang et al., 2023). Both Uzbekistan and Tajikistan of Central Asia encounter water shortages together with excessive grazing that leads to deteriorating soil structure and heightened emissions (Lukin, 2022). The analysis demonstrates the necessity to create distinctive policies which resolve the individual problems experienced by each nation.

Green Economics provides an appropriate framework that helps nations tackle challenges through sustainable agricultural approaches combined with efficient resource management. The implementation of regenerative farming techniques that incorporate crop rotation and cover cropping helps increase soil quality while capturing carbon which leads to emission reduction (Tan & Kuebbing, 2023). Organic fertilizers combined with renewable energy use in agriculture both protect the environment from agricultural stress and stimulate economic development according to Koondhar et al. (2021). Guilford University aligns its practices with Green Economics principles that focus on preserving ecosystems while allowing economic development. Literature demonstrates in detail all the variables and aspects connected to the data set employed in this analysis.

Martinez-Alier (1995) emphasized that making agriculture ready to cope with climate change necessitates advance awareness of the timing and nature of climate variations. Shabbir Alam et al. (2023) explored, that driven by population growth and shifting food consumption patterns, indicate that agricultural production must increase by a minimum of 70% by 2050 to meet rising consumer demands. According to them, the majority of predictions indicate that certain regions already grappling with food insecurity are at risk of experiencing reduced agricultural productivity, production stability, and income due to the impacts of climate change.

Taheripour et al. (2011) emphasized a significant future challenge: the need to satisfy the nutritional requirements of an expanding global population while utilizing fewer resources such as land, water, and energy. Their research forecasted that food prices are likely to remain elevated and volatile, impacting vulnerable populations in the developing world the most. The study concluded that while it is feasible to meet the projected seventy percent surge in food supplies by mid of this century, sustainability hinges on addressing challenges related to resource constraints and climate change, while minimizing environmental and social impacts. Angus et al. (2009) highlighted agriculture's prominent role in the UK, covering 77% of the land area. However, it contributes only 0.5% to GDP and 1.8% to employment. They predicted a growing distinction between policies for protecting resources and promoting ecosystem services and those encouraging domestic food production.

Badgley et al. (2007) discussed the concerns regarding the capability of organic agriculture to provide global food supplies. They analyzed a global dataset of 293 cases and discovered that, on average, organic yields are slightly lower in developed countries but higher in developing ones. The study proposed that leguminous cover crops could serve as substitutes for synthetic fertilizers. Appiah et al. (2018) investigated the relationship between agriculture and CO2 in emerging nations from 1971 till 2013. They utilized FMOLS and DOLS methods and found that economic growth, harvest, and cattle production indices meaningfully contributed to increase carbon dioxide releases. Additionally, an increase of one percent in economic growth together with crop production and livestock production led to 17 percent, 28 percent, and 28 percent elevation in carbon dioxide emissions. Their research used PMG estimator to demonstrate the importance of sustainable agricultural practices and environmentally friendly technologies for minimizing weather change impacts on food security as well as atmospheric conditions in emerging economies.

Waheed et al. (2018) researched the relationship between CO2 emissions and agriculture for Pakistan throughout the 1990s till 2014. The ARDL technique allowed researchers to measure how CO2 response to REC along with AG production and forest area in the short & long periods. Agricultural production generated significant positive effects on CO2 levels in the long-term period. The research found that examining agricultural carbon release becomes essential for Pakistan while showcasing that renewable energy and forests play an important role in reducing carbon dioxide pollutants. The quantity of CO2 emission linked to agricultural activity received investigation by Rehman et al. (2022) during the time period spanning from 1965 to 2018 in Nepal. Laboratory analysis of co-integration confirmed that agricultural production and land harvest areas together with NPK usage maintained a long-lasting connection with CO2 releases. Research findings indicated that higher fertilizer usage caused elevated carbon dioxide emissions to persist over short-term and long-term periods.

Khurshid et al. (2022) delved into the relationship between Pakistan's AG sector and CO2 emissions within the context of globalization from 1971 to 2021. The researchers applied the

NARDL model to study the dynamic aspects. The research demonstrated that AG shows variable responses to positive and negative shocks when globalization exists. An agricultural +ve shock produces higher CO2 emissions while negative shocks decrease such emissions. The research findings demonstrate that economic growth coupled with energy consumption and levels of economic globalization directly result in CO2 emissions leaks. During the period spanning from the 90s to 2014 Balsalobre-Lorente et al. (2019) studied Environmental Kuznets Curve in BRICS countries. The study found a U-shaped pattern between CO2 emissions and economic growth which proved that agricultural activities harm the environment.

The research of Ullah et al. (2021) tracked CO2 discharge patterns and economic growth together with agricultural modifications in Pakistan during the period from 1975 to 2018. The paper used an asymmetric ARDL model together with Granger causality analysis for its findings about symmetry in results. Then authors found that both agriculturalization and deagriculturalization processes created negative relationships with carbon release levels in Pakistan throughout the extended duration. M. A. Khan et al. (2020) developed research using a unified model approach to analyze economic impacts on Pakistani GDP from AG productivity changes because of environmental shifts. The researchers detected an enormous economic influence through their analysis which revealed Pakistan lost approximately $20 billion Real GDP.

Zhou et al. (2017) studied the relation between CO2 discharges and economic growth in 30 Chinese provinces between 1997 and 2014 while examining how much CO2 emissions separated from agricultural economic growth. NPK and seasoned rice farming and cattle operations represented the primary CO2 emission sources in AG production ventures and farming sectors and husbandry operations respectively. FAO (2020) showed the occurrence of rising climate impacts because of AG-related carbon emissions during the period from 2010 through 2014. The total CO2 emissions from agricultural sources increased from 5575 million metric tons (Mt) in 2010 to 5800 Mt during 2014.

Stern (2004) explored the potential of carbon sequestration in soil through altered agricultural management practices. The study indicated that improved crop yields with land abandonment result in substantial carbon savings, emphasizing the significance of overall management changes beyond soil carbon sequestration alone. According to Shabbir Alam et al. (2023), at the 26th Conference of Parties in Glasgow, India pledged to attain CO2 neutrality by 2070 and lower its carbon intensity. However, using data from 1990 to 2018, their study found that globalization, agricultural expansion, and higher population density contribute to long-term pollution, and the relationship between renewable energy and air quality forms a reversed U-shape, with a predicted threshold of around 45.75%

But there is also contradicting views too, as Du et al. (2023) employed ARDL bounds testing approach and DOLS methodology with annual data of 1990 to 2020 from Philippines and the study estimated that a 1% rise AG productivity, and forest area is associated with decreases in CO2 releases by 0.20%, and 3.46%, respectively. Huang et al. (2023) also appear to be on that side of literature as according to their study the relationship between ALC and GHG emissions followed an upward concave curve, with emissions increasing beyond an 8% ALC threshold during economic development and they advised to prevent converting more than 90% of AG land to other uses to achieve sustainable economic development and consider spatial effects, particularly in regions like Africa and Asia, when addressing global GHG emissions.

Rehman et al. (2022) estimated the same result in case of Bangladesh i.e. the reduced agricultural productivity increase CO2 emissions and explored the connection between AG and carbon dioxide (CO2) emissions in Bhutan. Analyzing data from 1980 to 2020, it investigated the effect of crop production, NPK, land allocation for crops, and agricultural employment on CO2 emissions. Their findings showed that crop productivity and land use for crops are positively related to CO2 emissions, while fertilizer consumption and agricultural employment have inverse connection in the long- term. In the short period, crop production and land allocation for crops increase CO2 emissions, while fertilizer use and agricultural employment reduce them. Their study recommends for Bhutan's government to instrument strategies to reduce CO2 emissions and enhance agricultural productivity.

Balogh (2022) investigated the factors behind CO2 emissions, with a focus on economic growth, AG, free trade agreements, and climate accords in non-European states, including the major emitting countries over the last 20 years. The findings indicate increased CO2 in these states and reduced effects of agriculture exports on GHG leaks, raising questions about trade-related emissions. While NAFTA encouraged emissions, EFTA, ASEAN, and MERCOSUR contributed to the reduction of emissions.

According to Du et al. (2023) environmental regulations, such as China's high-standard farmland construction policy, are instrumental for reducing AG carbon emissions. The study spanning from 2001 to 2019, based on data from 31 Chinese provinces, confirms that this form of environmental regulation, known as resource agglomeration, leading towards a significant average decrease of 3.9% in AG carbon emissions. This reduction is achieved by endorsing environmentally friendly technologies and enhancing crop cultivation methods.

Tang & Tan (2015) conducted an examination of reformative Agricultural businesses across Southeast Asia to investigate their soil carbon sequestration practices that fight against climate change. Their analysis of 92 empirical studies confirmed how different regenerative farming practices enhance soil organic carbon (SOC) across seventeen specific agricultural practices in various crops. The application of compost and manure as agricultural practices leads to higher GHG emissions that produce methane and nitrous oxide alongside potentially negating SOC increases.

The study conducted by Mendonça et al. (2020) analyzed environmental decline factors in West African states as linked to CO2 emissions. The study results showed different environmental degrading factors existed between nations with low and moderate and high CO2 emissions rates. West African nations with low incomes showed a pattern of surpassing their lower-middle income regional counterparts when it came to the release of CO2 emissions.

Haug & Ucal (2019) examined the impact of AG activities, GL (globalization), and RE generation on CO2 releases in Republic of Turkey using data of 1970 to 2017. The study utilized a range of statistical methods, including the G-H co-integration test and bootstrap ARDL, to analyze the dataset. The long-term estimations indicated that AG activities, as well as RE production and economic globalization, are linked to heightened environmental pollution, suggesting an adverse effect on CO2 emissions.

Yang et al. (2017) identified: Kyrgyzstan faced a fluctuating increase in CO2 from 2007 till 2015, with productions of structures contributing to fourteen percent of the (production based) CO2 increasing between 2012 and 2015. Whereas some other researchers have also expressed concerns about the water security in central Asian countries as Batmunkh et al. (2022) addressed the water crisis in Central Asia. The research predicted significant water security challenges in Turkmenistan and Uzbekistan, with the lowest pressure in Tajikistan and 10% in Kyrgyzstan.

There are also other researchers which focused on the macro side factors for the emissions as Doda (2014) delves with the relationship of CO2 emissions with Gross Domestic Product over business cycles. His finding was that emissions are pro cyclical, meaning they tend to move in the same direction as economic activity, emissions display greater cyclical volatility compared to GDP, signifying that environmental impacts can vary more substantially during economic fluctuations. Gyamfi et al. (2023) conducted a study which showed Agricultural economic growth is increased with increased AG CO2 releases in Africa. A quadratic relationship reveals that at a certain point, further agricultural growth becomes negatively related to CO2 emissions.

Huang et al. (2023) investigated the conjunction of CO2 emissions and intensity among countries with diverse urbanization and AG structures. Their findings revealed the formation of convergence clubs, often situated far from the global average emissions level. Shabbir Alam et al. (2023) research indicated that agricultural productivity and forest area contribute to emissions reductions. Du et al. (2023) assessed the impact of China's National Agricultural Sustainable Development Experimental Demonstration Zone policy on reducing agricultural carbon emissions. Their study demonstrated that the policy effectively reduces carbon emissions, with a focus on fiscal support intensity.

The impact of trade has been demonstrated in various studies. Appiah et al. (2018) assessed the influence of trade on CO2 and greenhouse gas emissions in the China-Japan-South Korea region, revealing that trade openness leads to increased greenhouse gas emissions. Importantly, their findings indicated that imports drive higher carbon emissions, while exports help reduce emissions in a country. Cheng et al. (2019) analyzed data from OECD and G20 countries from 1997 to 2019, uncovering that trade openness tends to elevate emissions. Hasanov et al. (2018) highlighted the important role of trade in shaping the generation of CB CO2, both in the short and longer period.

Huang et al. (2023) studied the unsymmetrical effects of TR on CO2 releases in Turkey, revealing that reduced exports in the long run are associated with lower CO2 emissions per capita. Akram et al. (2020) studied 65 BRI countries and observed that EX decrease CO2 in poor and rich nations, though rising them in poor income nations. On the other hand, IM elevate CO2 in poor nations but reduce them in average and rich nations.

Dou et al. (2021) found that the production of fertilizers could result in carbon emissions surpassing 1300 MtCO2eq/year if carbon-neutral fertilizers are not employed. Mielcarek-bocheńska & Rzeźnik (2021) recommended transitioning to organic fertilizers and RE in Pakistan to decrease CO2 emissions and improve cereal food production, leading to a more sustainable environment. Rehman et al. (2022) found that fertilizer, as an essential tool in agriculture, significantly contributes to GHG emissions.

Omri et al. (2014) examined 14 countries and uncovered a reduction in emission amount of 0.68 kilogram of CO2 equivalent per USD 1 value of food production worldwide output in 2000s to fewer 0.5 in 2014. Factors contributing to this reduced emission intensity include cereal yield, NPK, and agricultural material intensity. According to this study production of NP has significantly contributed to GHGs emissions, specifically CO2, as it dependence of fossil fuels.

Appiah et al. (2018) investigated the combined influence of GDPG on CO2 in 23 emerging nations, finding that a one percent rise in GDPG causes a 0.23% rise in CO2 releases. Meanwhile, Mendonça et al. (2020) constructed a hierarchical model of the fifty largest economies to examine the impact of Gross Domestic Product on carbon emissions. Their findings indicate that a one percent rise in GDP results in a 0.3 percent rise in CO2.

Batmunkh et al. 2022 presented a study using the ARDL approach, revealing that EG (Economic Growth) inversely impact environmental sustainability in the LR (long run). Omri et al., 2014 investigated the connection among RE, economic growth, and CO2 emissions across 15 largest RE consumer economies. Using FMOLS and VECM estimation techniques, they established the effectiveness of RE in promotion of economic growth and reducing CO2 releases. The FMOLS method revealed that renewable energy contributes positively to economic growth while curbing CO2 discharges.

Anser et al. (2020) found out that POP size and GDP p/c are the important cause of CO2 discharges in SAARC. He used augmented STIRPAT model and fixed effect regression. Similarly, (Balogh, 2022) sought to establish this relationship in Europe using data from 22 countries, and their findings demonstrated a notable effect of regional population growth on CO2 discharges and urban land utilization expansion in West Europe.

Despite the growing body of research on agriculture and carbon emissions, there is a notable gap in understanding the asymmetric effects of agricultural practices on CO_2 emissions. Most studies have focused on linear relationships, overlooking the potential for positive and negative shocks in agricultural activity to have differing impacts on emissions. This study addresses this gap by employing the NPARDL model, which allows for the examination of both short- and long-term asymmetries in the relationship between agriculture and carbon emissions. The findings contribute to the literature on Green Economics by providing insights into how agricultural policies can be designed to balance economic growth with environmental sustainability.

Research Methodology

Model

The primary goal of this study is to examine the unequal effects of agriculture on CO_2 in SCO countries. Building on the research conducted by Khan et al. (2020) and Salisu and Isah (2017), the study's model formulation is outlined below:

$$CO_2 = F(AG\ VA, REC, POP\ G, GDP, TRADE, NPK) \quad (1)$$

$$CO_2 = F(AG\ VA^{+}, AG\ VA^{-}, REC, POP\ G, GDP, TRADE, NPK) \quad (2)$$

$$\mathrm{CO}_{2it} = \beta_0 + \beta_1 AG\ VA^{+}{}_{it} + \beta_2 AG\ VA^{-}{}_{it} + \beta_3 REC_{it} + \beta_4 POP\ G_{it} + \beta_5 \mathrm{GDP}_{it} + \beta_6 \mathrm{TRADE}_{it} + \beta_7 NPK_{it} + \varepsilon_{it} \quad (3)$$

Here, carbon emission is denoted as CO2, agricultural value added as AG VA, gross domestic product as GDP, renewable energy consumption as REC, and fertilizer consumption as NPK. Additionally, population growth is represented by POP G, and trade is indicated by the variable TRADE. Similarly, $AG\ VA^{+}$ and $AG\ VA^{-}$ indicate positive and negative growth in AG while ε represents the error term, which has a Gaussian distribution with a mean of zero and a variance of constant. Furthermore, "i" denotes individual countries and "t" signifies the time duration spanning from 1992 to 2020 in the analysis. β_0 represents the model's intercept, while β_1, β_2, β_3, β_4, β_5, β_6 and β_7 represents the coefficients for positive AG value added, negative AG value added, renewable energy consumption, population growth, gross domestic product, trade, and fertilizer consumption, respectively.

Data

The data used in this investigation comprises socioeconomic indicators of the Shanghai Cooperation Organization (SCO) countries (spanning from 1992 to 2020), a significant coalition in the Eastern world. The variables investigated include the logarithm of CO2 emissions (measured in kilotons), log transformed NPK (in kilograms per hectare of arable land), along with other parameters presented as percentages. These variables encompass Trade (as a % of GDP), REC (as a % of total final EC), POP G (annual percentage), AG VA (as a % of GDP), and GDP growth (yearly percentage). This dataset, taken from the World Development Indicators, provides a comprehensive collection of global socioeconomic data. Within the context of zero-carbon strategies, the SCO holds pivotal significance, playing a crucial role in shaping and implementing environmentally sustainable policies across its member nations. The SCO's collective efforts and strategic collaborations in formulating and executing zero-carbon initiatives render it a central actor in the pursuit of a greener future in the Eastern world.

This analysis holds profound significance in understanding the nuanced interplay between agricultural practices, environmental impact, and economic development within the SCO countries. Understanding how positive and negative agricultural value-added influence CO2 emissions provides a pathway to tailor interventions that balance economic growth with environmental conservation. The data of all the SCO member countries is included except Islamic Republic of Iran due to the unavailability of data. The SCO member countries included in the analysis are China (CHN), India (IND), Pakistan (PAK), Russia (RUS), Tajikistan (TAJ), Uzbekistan (UZB), Kyrgyzstan (KYR) and Kazakhstan (KAZ).

Variables

The study utilizes the following variables: CO_2 emissions, NPK (Fertilizer consumption), Trade (% of GDP), REC (Renewable energy consumption), POP G (Population growth), AGR VA (Agriculture, forestry and fishing value added) and GDP growth.

CO_2 (kt) measures the size of carbon dioxide discharged in the climate, providing insights into a country's environmental impact and adherence to emission reduction strategies. NPK (kilograms per hectare of arable land) represents the magnitude of fertilizers used in agricultural practices, influencing crop yield and soil health. Trade (% of GDP) reflects a country's trade intensity relative to its economic output, offering insights into economic globalization and its potential environmental implications. REC (% of total final EC) signifies a nation's reliance on sustainable energy bases, crucial in reducing CO_2 and fostering ecological sustainability. Population growth (annual %) measures demographic changes and their influence on environmental pressures and resource utilization strategies. AG VA (% of GDP) highlights the significance of these sectors in the economy and their potential impact on carbon emissions as Gyamfi et al. (2023) established that AG VA is a crucial factor in comprehending the ecological footprint of the E7 economies, encompassing both rich and developing countries. These studies highlight the significance of AG VA as a holistic measure of agriculture's impact on economic development and its environmental effects. GDP growth (annual %) represents the annual growth rate of GDP, reflecting the pace of economic expansion and its correlation with environmental impacts. These variables collectively provide a comprehensive understanding of the causes inducing climate sustainability and economic development. The specifics of the variables, including the descriptions, their units, and the sources, is summarized in Table 1.

Table 1. Variables, description, and their units. Sources: https://databank.worldbank.org/source/world-development-indicators

VARIABLES	DESCRIPTION	UNIT
CO_2	CO2 emissions	Kilo Ton (kt)
AGR VA	AG, forestry, and fishing, value added	% of GDP
REC	Renewable energy consumption	% of total final energy consumption
GDP	GDP growth	Annual % (Constant US 2015$)
POP G	Population growth	Annual %
TRADE	Trade	% of GDP
NPK	Fertilizer Consumption	kilograms per hectare of arable land

Econometric Methods

Cross-Sectional Dependence

To utilize suitable panel econometric methodologies, the initial step involves investigating the potential presence of cross-sectional interdependence amongst the chosen countries. In essence, panel econometric approaches fail to address cross-sectional dependencies and might yield misleading outcomes. To ascertain the existence of such interdependencies within variables like CO_2 emissions, AG value-added, renewable energy consumption, population growth, GDP growth, fertilizer consumption, and trade, we employed the CSD (Cross-Section Dependence) test as advocated by Pesaran (2004). The H0 for the CSD test assumes independence amongst cross-sections while the H1 considers the possibility of CSD. Here are the test statistics:

$$CD = \sqrt{\frac{2T}{N(N-1)}} \left(\sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \rho_{ij} \right), N(01) \quad (4)$$

Panel Unit Root Test

Due to the likelihood of substantial CSD within the dataset, it is essential to proceed with a panel unit root test that specifically addresses this concern. Hence, in this study, we employed the CIPS unit root test, developed by Pesaran in 2007, known for its capability to effectively manage the challenge of CSD in the analysis.

The equation for CIPS is given as:

$$\Delta y_{it} = \alpha_i + \rho_i y_{it-1} + \beta_i \bar{y}_{t-1} + \sum_{j=0}^{k} \Upsilon_{ij} \Delta \bar{y}_{it-1} + \sum_{j=0}^{k} \delta_{ij} y_{it-1} + \varepsilon_{it} \quad (5)$$

The deterministic term is signified by α_i, the order of lag is denoted by k, and t signifies the CS averages, as specified in the context. As outlined by Pesaran (2007), the approach addresses CSD among the observed states, ensuring consistent results even with limited sample sizes. Unlike the statistics OF CIPS derived applying CADF, the statistic for CIPS is presented as

$\widehat{CIPS} = N^{-1} \sum_{i=1}^{N} CDF_i$ (6)

Where, CDF stands for CS Augmented Dickey-Fuller (CADF).

Panel Co-integration Test

When we have established that there is CSD then the utilization of co-integration tests, particularly the Westerlund (2005) co-integration test, holds paramount importance in the analysis. These tests are pivotal in determining whether long-term relationships exist between variables within panel data, offering insights into the interdependencies among key socioeconomic indicators. In the context of this study, evaluating co-integration is crucial as it helps discern whether certain variables, such as GDP growth, trade, renewable energy consumption, and carbon emissions, move together in the long run across the SCO countries. The selection of the Westerlund (2005) test over simpler methods is justified by its specific adaptability to panel data, allowing for a comprehensive assessment of co-integration while accommodating heterogeneity and potential cross-sectional dependencies within the dataset. Unlike conventional co-integration tests, the Westerlund method is tailored for panel data analysis, making it more suitable for examining the long-term relationships among variables across multiple countries simultaneously. We are going to test both the linear and nonlinear models with it. The test statistics is given as:

$$VR = \sum_{i=1}^{N} \sum_{t=1}^{T} \widehat{E}_{it}^2 \left(\sum_{i=1}^{N} \widehat{R}_i \right)^{-1} \quad (7)$$

Where

$\widehat{E}_{it} = \sum_{j=1}^{t} \widehat{e}_{ij}$, $\widehat{R}_i = \sum_{t=1}^{T} \widehat{e}_{it}^2$, and eb_{it} is the residuals from the panel-data regression model.

Nonlinear Panel Autoregressive Distributed Lag (NPARDL) Model

In the study, we implement the NPARDL model, outlined by Salisu and Isah (2017). The rationale behind employing this method is grounded in several key aspects. Firstly, it is well-suited for datasets with extensive time dimensions and limited cross-sectional aspects. Secondly, crucially aligned with the focus of this research, it facilitates the identification of nonlinear asymmetries. Thirdly, particularly observed in AG, this model takes into consideration the inherent heterogeneity presents in the data. Lastly, its applicability extends to scenarios where the integration order does not surpass I(1).

We have opted for the PMG (Pooled Mean Group) estimator over the MG (Mean Group) estimator to estimate dynamic heterogeneous panel data models. This choice is motivated by the PMG's capability to generate consistent long-run coefficients across countries in the panel, also acknowledging the presence of heterogeneous short-run coefficients, as recommended by Bangake & Eggoh (2012). Economically, this choice is grounded in the understanding that the short-term link between CO_2 emissions, AGR VA, REC, POP G, GDP, NPK, and Trade may differ across cross-sections, yet exhibit a convergent behavior in the long run. It's worth noting that alternative approaches like FMOLS and DOLS predominantly focus on exploring long-run association among the series, and cannot capture short-term dynamics, reinforcing the suitability of PMG for this study's objectives.

The panel ARDL's symmetrical version is characterized as:

$$\Delta CO_{2it} = \beta_{0i} + \beta_{1i}CO_{2i,t-1} + \beta_{2i}AG\ VA_{t-1} + \beta_{3i}REC_{t-1} + \beta_{4i}POP\ G_{t-1} + \beta_{5i}GDP_{t-1} + \beta_{6i}TRADE_{t-1} + \beta_{7i}NPK_{t-1} + \sum_{j=1}^{N1}\lambda_{ij}\,\Delta CO_{2i,t-j} + \sum_{j=0}^{N2}\gamma_{ij}\,\Delta AG\ VA_{t-j} + \sum_{j=0}^{N3}\eta_{ij}\,\Delta REC_{t-j} + \sum_{j=0}^{N4}\alpha_{ij}\,\Delta POP\ G_{t-j} + \sum_{j=0}^{N5}\varphi_{ij}\,\Delta GDP_{t-j} + \sum_{j=0}^{N6}\delta_{ij}\,\Delta TRADE_{t-j} + \sum_{j=0}^{N7}\psi_{ij}\,\Delta NPK_{t-j} + \varepsilon_{it} \quad (8)$$

$$i = 1, 2, 3, \dots N; \quad t = 1, 2, 3, \dots T.$$

In this equation, CO_2 represents the logarithm of carbon emissions observed across time period "t" within each cross-sectional unit "i". AG VA_t signifies AG value added at period "t", while $TRADE_t$, POP G_t, GDP_t, REC_t, and NPK_t correspond to trade, population growth, gross domestic product growth, renewable energy consumption, and the log of fertilizer consumption, same as the sampled units are denoted by "i," , "t" signifies the time periods. So, it is feasible to reframe equation (8) to incorporate the EC (error correction) term as shown below:

$$\Delta CO_{2it} = \delta_i\, v_{i,t-1} + \sum_{j=1}^{N1}\lambda_{ij}\,\Delta CO_{2i,t-j} + \sum_{j=0}^{N2}\gamma_{ij}\,\Delta AG\ VA_{t-j} + \sum_{j=0}^{N3}\eta_{ij}\,\Delta REC_{t-j} + \sum_{j=0}^{N4}\alpha_{ij}\,\Delta POP\ G_{t-j} + \sum_{j=0}^{N5}\varphi_{ij}\,\Delta GDP_{t-j} + \sum_{j=0}^{N6}\delta_{ij}\,\Delta TRADE_{t-j} + \sum_{j=0}^{N7}\psi_{ij}\,\Delta NPK_{t-j} + \varepsilon_{it} \quad (9)$$

Where,

$v_{i,t-1} = CO_{2i,t-1} - \phi_{0i} - \phi_{1i}AG\ VA_{t-1} - \phi_{2i}REC_{t-1} - \phi_{3i}POP\ G_{t-1} - \phi_{4i}GDP_{t-1} - \phi_{5i}TRADE_{t-1} - \phi_{6i}NPK_{t-1}$, represents the linear ECT for every unit, while the parameter δi signifies the speed of adjustment term for EC term for each unit, that is equal to β_{1i}. The parameters $\phi_{0i}, \phi_{1i}, \phi_{2i}, \phi_{3i}, \phi_{4i}, \phi_{5i}\ and\ \phi_{6i}$ are computed as $-\frac{\beta_{0i}}{\beta_{1i}}, -\frac{\beta_{2i}}{\beta_{1i}}, -\frac{\beta_{3i}}{\beta_{2i}}, -\frac{\beta_{4i}}{\beta_{3i}}, -\frac{\beta_{5i}}{\beta_{4i}}$ $and\ \frac{\beta_{6i}}{\beta_{5i}}$ correspondingly. The absence of AG decomposition into +ve and -ve shocks in equations (8) and (9) indicates that the assumption of AGR having a symmetrical impact on CO_2 emissions is persistent in this situation.

In contrast to the symmetrical circumstances, the NPARDL, an asymmetric version of the panel ARDL, permits an unequal reaction of CO_2 to agriculture. This model anticipates that positive and negative impacts resulting from agriculture will have varying effects on CO_2. Therefore, the equation (8) is expressed in its asymmetric form as follows:

$$\Delta CO_{2it} = \beta_{0i} + \beta_{1i}CO_{2i,t-1} + \beta_{2i}^{+}AG\,VA_{t-1}^{+} + \beta_{2i}^{-}AG\,VA_{t-1}^{-} + \beta_{3i}^{+}REC_{t-1}^{+} + \beta_{3i}^{-}POP\,G_{t-1}^{+} + \beta_{4i}GDP_{t-1} + \beta_{5i}TRADE_{t-1} + \beta_{6i}NPK_{t-1} + \sum_{j=1}^{N1}\lambda_{ij}\,\Delta CO_{2i,t-j} + \sum_{j=0}^{N2}(\gamma_{ij}^{+}\Delta AG\,VA_{t-j}^{+} + \gamma_{ij}^{-}\Delta AG\,VA_{t-j}^{-}) + \sum_{j=0}^{N3}(\eta_{ij}^{+}\Delta REC_{t-j}^{+}) + \sum_{j=0}^{N4}\alpha_{ij}\,\Delta POP\,G_{t-j} + \sum_{j=0}^{N5}\varphi_{ij}\,\Delta GDP_{t-j} + \sum_{j=0}^{N6}\delta_{ij}\,\Delta TRADE_{t-j} + \sum_{j=0}^{N7}\psi_{ij}\,\Delta NPK_{t-j} + \varepsilon_{it} \quad (10)$$

Where, $AG\,VA^{+}$ and $AG\,VA^{-}$ denote the +ve and –ve AG value added shocks correspondingly. The long-term elasticity coefficients for AG^{+}, AG^{-}, renewable energy consumption, population growth, GDP growth, trade, and fertilizer consumption are calculated as:

$\beta_{AG\,VA}^{+} = -\frac{\beta_{2i}^{+}}{\beta_{1i}}$ (11) (Long-run elasticity of CO_2 to AG^{+})

$\beta_{AG\,VA}^{-} = -\frac{\beta_{2i}^{-}}{\beta_{1i}}$ (12) (Long-run elasticity of CO_2 to AG^{-})

$\beta_{REC} = -\frac{\beta_{3i}}{\beta_{1i}}$ (13) (Long-run elasticity of CO_2 to REC)

$\beta_{POP\,G} = -\frac{\beta_{4i}}{\beta_{1i}}$ (14) (Long-run elasticity of CO_2 to POP G)

$\beta_{GDP} = -\frac{\beta_{5i}}{\beta_{1i}}$ (15) (Long-run elasticity of CO_2 to GDP)

$\beta_{TRADE} = -\frac{\beta_{6i}}{\beta_{1i}}$ (16) (Long-run elasticity of CO_2 to trade)

$\beta_{NPK} = -\frac{\beta_{7i}}{\beta_{1i}}$ (17) (Long-run elasticity of CO_2 to NPK)

The +ve and –ve shocks are calculated as the +ve and -ve partial sum decompositions of AG VA changes, as presented below:

$$AG\,VA_{t}^{+} = \sum_{k=1}^{t}\Delta\,AG\,VA_{ik}^{+} = \sum_{k=1}^{t}\max(AG\,VA_{ik}, 0) \quad (18)$$

$$AG\,VA_{t}^{-} = \sum_{k=1}^{t}\Delta\,AG\,VA_{ik}^{-} = \sum_{k=1}^{t}\min(AG\,VA_{ik}, 0) \quad (19)$$

Equation (9) can be reformulated to contain the ECT will be:

$$\Delta CO_{2it} = \tau_i\xi_{i,t-1} + \sum_{j=1}^{N1}\lambda_{ij}\,\Delta CO_{2i,t-j} + \sum_{j=0}^{N2}(\gamma_{ij}^{+}\Delta AG\,VA_{t-j}^{+} + \gamma_{ij}^{-}\Delta AG\,VA_{t-j}^{-}) + \sum_{j=0}^{N3}(\eta_{ij}^{+}\Delta REC_{t-j}^{+}) + \sum_{j=0}^{N4}\alpha_{ij}\,\Delta POP\,G_{t-j} + \sum_{j=0}^{N5}\varphi_{ij}\,\Delta GDP_{t-j} + \sum_{j=0}^{N6}\delta_{ij}\,\Delta TRADE_{t-j} + \sum_{j=0}^{N7}\psi_{ij}\,\Delta NPK_{t-j} + \varepsilon_{it} \quad (20)$$

The ECF (ξ_(i,t-1)) symbolizes the long-term equilibrium in the NPARDL model, as outlined in equation (20), with its corresponding (parameter) τ_i quantifying the adjustment speed, signifying the duration for the system to reach its long-term equilibrium in the presence of a shock.

Table 2. Descriptive statistics

VARIABLE	OBSERVATIONS	MEAN	STD. DEV.	MIN	MAX
CO_2	232	12.05254	2.455344	7.665664	16.20836
NPK	232	3.815312	1.605971	-.9056124	6.17429
GDP	232	4.033051	6.409459	-29	14.23086
POP G	232	1.216348	.9431636	-2.06204	3.092079
Trade	232	63.41353	33.28161	18.4331	181.5901
REC	232	24.78522	21.00543	.72	64.58
AG VA	232	23.75021	2.292987	19.94561	27.72248

Descriptive statistics for all the variables of SCO countries are presented in Table 2. The minimum values for carbon emissions, fertilizer consumption, GDP growth, population growth, trade, renewable energy consumption and AG value added are 7.6656, -90561, -29, -2.062, 18.431, .72, 19.945 respectively, while the maximum values are 16.208, 6.1742, 14.23, 3.0920, 181.59, 64.58 and 27.722 respectively. The mean of logged carbon emission and logged fertilizer consumption is 12.052 and 3.8153 while their standard deviation is 2.4553 and 1.6059 respectively. GDP growth, population growth, trade, renewable energy consumption, and AG value added has mean values of 4.0330, 1.2163, 63.4135, 24.785 and 23.750 respectively while their standard deviations are 6.4094, .94316, 33.281, 21.005 and 2.2929 respectively.

Results and Discussion

Pesaran CD Test

Initially, we investigated whether there was CSD in the chosen panel. The results of the test for CSD can be found in Table 3. These results suggest that our CS (cross-sections) are dependent, as indicated by the significant test statistics obtained from the CSD (Cross-section dependency) test. The outcomes consistently reject the H0 of CS (cross-sectional) independence across variables, implying the transmission of shocks across the SCO countries and indicating a significant level of interconnectedness among the studied variables.

Table 3. Pesaran (2004) CD Test Results

VARIABLE	CD TEST	P VALUE	CORR	ABS(CORR)
CO_2	10.27	0.000	0.360	0.440
AG VA^+	23.48	0.000	0.824	0.824
AG VA^-	26.44	0.000	0.928	0.928
NPK	5.16	0.000	0.181	0.367
GDP	8.61	0.000	0.302	0.429
POP G	-1.93	0.054	-0.068	0.430
Trade	3.31	0.001	0.116	0.311
REC	7.41	0.000	0.260	0.336

CIPS Panel Unit root Test

After confirming the occurrence of CSD, the next step is to carry out the CIPS unit root test introduced by Pesaran in 2007. We chose this test due to its ability to address the issue of CSD. The findings, detailed in Table 4, reveal that all variables, except GDP growth and Trade, exhibit a first-order integration, I (1). Trade and GDP growth show stationary behavior at the level, I (0). Therefore, the appropriateness of using the NPARDL model for this study is confirmed. By employing the PMG method to evaluate the NPARDL, it is verified that none of the variables demonstrate an integration order of 2, I (2).

Table 4. Results CIPS PUR Test by Pesaran (2007)

VARIABLES	LEVEL	LEVEL	1ST DIFFERENCE	1ST DIFFERENCE	ORDER
	Intercept	Intercept and trend	Intercept	Intercept and trend	
CO_2	-1.706	-1.415	-3.931***	-4.049***	I(1)
AG VA+	-2.315	-2.561	-5.471***	-5.585***	I(1)
AG VA^-	-2.654	-3.076	-4.411***	-4.414***	I(1)
POP G	-1.215	-1.872	-3.328**	-3.432**	I(1)
NPK	-2.379	-2.957	-5.219***	-5.262***	I(1)
GDP	-3.526***	-3.526***	-3.522***	-3.474***	I(0)
Trade	-2.922***	-3.162***	-4.971***	-4.880***	I(0)
REC	-2.028	-2.107	-4.413***	-4.767***	I(1)

*Note: Level of significance is signified by *** p<0.01, ** p<0.05, * p<0.1.*

Westerlund Co-Integration Test

Following the panel unit root test, it's crucial to examine the co-integration among the variables, essentially checking for their long-term relationship. To achieve this, we used the co-integration test developed by Westerlund to comprehend the nature of the relationship between these variables across SCO countries. The results of Table (5) showcase the outcomes of the Westerlund (2005) (co-integration test) for linear relationships. These findings specify the absence of a long-term linear relationship amongst CO_2, REC, POP G, GDP, Trade, and NPK. The lack of symmetrical co-integration prompts the need to explore asymmetric co-integration, underscoring the significance of detecting nonlinear relationships. The outcomes of the nonlinear co-integration, which are also elaborated in Table (5), validate a significant co-integration among CO_2, REC, POP G, GDP growth, trade, and fertilizer consumption.

Table 5. Test Results for Westerlund (2005) Co-integration

VARIANCE RATIO	STATISTIC	P-VALUE
Co-integration results of linear model	-0.2985	0.3826
Co-integration results of non-linear model	2.1591	0.0154

NPARDL Results

The first panel of Table 6 showcases the short-term outcomes derived from the nonlinear panel ARDL, whereas the subsequent panel records the long-term findings obtained through the NPARDL model. These outcomes stem from employing the PMG estimation technique. In the first panel of Table 6, the results of the EC (error-correction) term show a significant -ve effect, suggesting that afterward a shock, the structure moves towards long-term equilibrium. This discovery within the EC term also offers insight into the presence of non-linear co-integration between AG VA and CO_2.

Table 6. Short and long-run results of non-linear panel ARDL

Short-run results of NPARDL			
Dependent variable: CO_2			
VARIABLE	COEFFICIENT	T-STATISTIC	PROB.
ECT	-0.108216	-2.343402	0.0204
AG VA^{+}	-0.002565	-0.248280	0.8043
AG VA^{-}	-0.007037	-2.831154	0.0053
REC	-0.046829	-3.492469	0.0006
POP G	-0.027828	-0.804331	0.4225
GDP	-0.000897	-0.652171	0.5153
TRADE	0.000783	0.144969	0.8849
NPK	0.022514	0.860681	0.3908
Constant	1.303396	2.185713	0.0304
Log-likelihood	477.2337		
Long-run results for NPARDL			
AG VA^{+}	0.039324	4.080035	0.0001
AG VA^{-}	-0.051085	-4.223621	0.0000
REC	-0.036651	-6.415778	0.0000
POP G	0.075319	1.885345	0.0613
GDP	0.016423	2.529345	0.0124
TRADE	0.004918	2.301300	0.0227
NPK	-0.039249	-0.427225	0.6698

Note: Model is estimated by PMG

Relationship between Agriculture and Carbon Emissions

There is a rising trend of AG (agriculture) based CO_2 and it rapidly increasing with time (FOA 2013). Both our short-run and long-run results suggests that negative shocks in AG value added significantly mitigate the CO_2 across the SCO countries. The findings indicate that the short-run elasticity of CO_2 concerning negative AG value added stands at -0.007. This signifies that a 1% decline in AG notably reduces CO_2 by 0.007% in the short run. Whereas, in the long-run elasticity of CO_2 concerning negative AG is recorded at -0.051, indicating: 1% decrease in AG significantly decrease CO_2 by 0.051% in long-run. The magnitude of the long-term elasticity is notably greater than that of the short-term, indicating that the negative influence of agriculture on CO_2 intensifies gradually over time. The results also suggest that the short-term elasticity of

CO_2 in relation to positive AG VA is not statistically significant. In contrast, the long-term elasticity of carbon emissions with respect to positive agriculture value added is 0.039. This implies that a one percent rise in AG significantly increases CO2 by 0.039%. Therefore, the positive impact of AG significantly contributes to CO_2 across SCO countries. The impact of agriculture (AG) on CO_2 significantly rises, and their relationship for BRICS countries follows a U-shaped pattern. (Balsalobre-Lorente et al., 2019). In summary, positive shocks in AG correlate with a notable increase in carbon emissions, while negative shocks demonstrate a substantial decrease in CO_2 levels.

Relationship between Renewable Energy Consumption, Population Growth, GDP, Trade, Fertilizer Consumption and Carbon Emissions

The CO_2 emissions are negatively connected with REC as the positive REC significantly mitigate the carbon emissions (Akram et al., 2020). Effectively utilizing renewable energy contributes inversely to energy intensity and carbon amount so both of which indicate a reduction in CO_2 (Lu, 2017). Our findings indicate that the short-term elasticity of CO_2 to REC is significantly -0.046, suggesting that a one percent rise in REC will decrease CO_2 emissions by 0.046%. In the long run, this value becomes -0.036, indicating that a one percent increase in REC will significantly reduce CO_2 by 0.036%.

The GDP is positively associated with CO_2 emissions (Mendonca et al., 2020). This is due to the fact that rising GDP causes the nation's aggregate demand to rise. (Omri and Kahouli 2014). The long-run elasticity of CO_2 relative to GDP is 0.016 which means 1 percent increase in GDP will increase the CO_2 by 0.016 percent. Whereas short-run results are insignificant. Trade is positively linked with the CO_2 (Wang et al., 2023). According to our results the long-term elasticity of carbon relative to trade across SCO countries is 0.004 but in short run it is insignificant.

Population size and per capita GDP emerge as the primary factors driving elevated CO_2 within SAARC nations (Anser et al., 2020). Population growth is one of the primary factors for the increase in pollution and is responsible for the environmental degradation (Sarkodie et al., 2020). The long-term association between CO_2 and POP G is +ve and insignificant but we have literature to believe that this relationship exists. The short-run relationship is also insignificant in the case of POP G. The results for NPK appear to be insignificant in our model.

Wald Test

For the estimation of asymmetrical analysis, the Wald test is applied (Vasichenko et al., 2020). To assess the distributional asymmetry of the QNARDL model across various quantiles, Wald test is conducted (Bouri et al., 2018). The outcomes from the Wald test confirmed the existence of nonlinear effects originating from AG VA on CO_2. These findings, presented in Table 7, reject the null hypothesis proposing same effects from positive and negative shocks in AG VA. Consequently, the results establish the presence of an asymmetric relationship between CO_2 and AG VA.

Table 7. Wald Test Results

NULL HYPOTHESIS: AGR VA^+ - AGR VA^-=0	VALUE	PROB.
F-statistic	25.63066	0.0000
Chi-square	25.63063	0.0000

*Note: α is *** p<0.01. ** p<0.05. * p<0.1.*

Dumitrescu Hurlin Panel Causality Test

To examine Granger Causality, we employed the Pairwise Panel Causality Test introduced by Dumitrescu and Hurlin in 2012 and the outcomes are displayed in Table 8. The pairwise DH causality test reveals that a +ve shock in AG VA significantly leads to increased CO_2 in SCO countries. However, the reverse causation, where CO_2 causes positive shocks in AG value added, is not supported. This implies a one-way causality from AGR VA^+ to CO^2. Similar results are observed for negative AG shocks, where AG VA^- significantly causes CO^2, but CO^2 does not reciprocally cause AG VA^-. Thus, policies related to AG can influence carbon emissions, but the reverse is not true in SCO countries. Additionally, renewable energy consumption, population growth, and GDP all exhibit significant causes of carbon emissions, while carbon emissions do not influence them in return. Interestingly, fertilizer consumption does not cause carbon emissions, and vice versa, according to the results in SCO countries.

Table 8. Pairwise Dumitrescu Hurlin Panel Causality Test Results

Null hypothesis	W-Stat.	Zbar-Stat.	Prob.
AGR VA^+ does not homogeneously cause CO_2	15.2951	24.4546	0.0000
CO_2 does not homogeneously cause AGR VA^+	1.20989	0.21160	0.8324
AGR VA^- does not homogeneously cause CO_2	9.95540	15.2640	0.0000
CO_2 does not homogeneously cause AGR VA^-	0.90635	-0.31086	0.7559
TRADE does not homogeneously cause CO_2	12.5451	2.15738	0.0310
CO_2 does not homogeneously cause TRADE	8.38980	0.38049	0.7036
REC does not homogeneously cause CO_2	3.68002	4.46308	0.0000
CO_2 does not homogeneously cause REC	3.96684	4.95675	0.0912
POP G does not homogeneously cause CO_2	8.86063	13.3797	0.0000
CO_2does not homogeneously cause POP G	1.36078	0.47129	0.6374
GDP does not homogeneously cause CO_2	6.63914	9.03986	0.0000
CO_2 does not homogeneously cause GDP	0.70386	-0.61896	0.5359
NPK does not homogeneously cause CO_2	3.37022	-0.85818	0.3908
CO_2 does not homogeneously cause NPK	4.92955	0.25585	0.7981

Note: The null hypothesis is one-way causality

Conclusions and policy suggestions

Climate change represents the paramount concern that confronts humans in the present era. Put simply, climate change encompasses enduring modifications in temperature and atmospheric conditions that will ultimately alter the living conditions on earth. (UNFCC, 2022). Every 1000 GT of cumulative CO^2 emissions is estimated to potentially lead to a rise in worldwide temperature, ranging from 0.27 - 0.63 degrees Celsius, with a central estimate of 0.45°C (IPCC, 2021). One of the contributors to carbon emissions is AG. While extensive research has been conducted on various factors such as international trade, energy, urbanization, and deforestation, there is a clear gap in research of AG as a significant contributing factor.

To achieve the research objective, the initial stage consisted of evaluating the existence of cross-sectional dependency, which uncovered a significant level of CSD among the SCO countries. This shows, a shock in every SCO country has a significant influence on the entire panel. The NPARDL model was used to perform the estimation. The hypothesis of a linear long-run relationship has been disproved by the asymmetric co-integration results, which instead support the existence of an asymmetric long-run relationship between AG VA and CO_2. Additionally, PMG estimates show that a -ve shock on agriculture considerably lowers CO_2 in SCO nations over the long and near terms. On the other hand, while statistically negligible in the short term, a +ve shock on AG VA has a considerable positive effect on CO_2 over the long term. The findings show that CO_2's short-run elasticity concerning negative AG value added is -0.007. This means that, in the short run, a 1% decrease in agriculture significantly lowers CO_2 by 0.007%. On the other hand, the long-run elasticity of CO2 with respect to negative agriculture is measured at -0.051, meaning that a 1% reduction in agriculture will result in a long-term reduction of CO2 of 0.051%. The findings also show that there is statistically little evidence of the short-run elasticity of CO2 with respect to positive agriculture. On the other hand, 0.039 represents the long-run elasticity of carbon emissions with respect to positive agriculture. This means that an increase in agriculture of 1% results in a significant rise in CO2 emissions of 0.039%. Also, the results from the Wald Test prove that agriculture has non-linear effect on CO_2, because +ve and –ve series impact differently.

To check the granger causality, we used DH Panel Causality Test. The pairwise DH causality test reveals that a positive shock in agriculture value added significantly leads to increased CO_2 emissions in SCO countries. However, the reverse causation, where CO_2 emissions cause positive shocks in agriculture value added, is not supported. This implies a one-way causality from AG VA^+ to CO^2. Similar results are observed for negative agriculture shocks, where AG VA^- significantly causes CO^2, but CO^2 does not reciprocally cause AG VA^-.

Policy Recommendations

The results of our study offer valuable insights for presenting policy recommendations for mitigating carbon emissions in SCO countries. First, given that negative shocks in agriculture value added have a significant impact on reducing carbon emissions, policies should focus on promoting sustainable agricultural practices and technologies. Initiatives that increase efficiency, reduce emissions, and promote environmentally friendly agricultural methods can be promoted to harness the long-term benefits of decreasing carbon emissions. Now that positive agriculture has an impact on increasing carbon emissions, policymakers should consider taking measures to balance agricultural growth with environmental sustainability. This could involve the adoption of eco-friendly farming practices, investment in cleaner technologies, and the promotion of agricultural policies that prioritize environmental conservation. Furthermore, our results suggest the importance of REC in reducing CO_2 emissions. Policymakers can prioritize the embracing of RE sources to achieve environmental objectives. The apparent insignificance of fertilizer consumption in our model suggests a need for further investigation of broader factors influencing carbon emissions in the agricultural sector.

References

Akram, R., Majeed, M. T., Fareed, Z., Khalid, F., & Ye, C. (2020). Asymmetric effects of energy efficiency and renewable energy on carbon emissions of BRICS economies: Evidence from nonlinear panel autoregressive distributed lag model. *Environmental Science and Pollution Research*, *27*, 18254–18268. https://doi.org/10.1007/s11356-020-08353-8

Angus, A., Burgess, P. J., Morris, J., & Lingard, J. (2009). Agriculture and land use: Demand for and supply of agricultural commodities, characteristics of the farming and food industries, and implications for land use in the UK. *Land Use Policy*, *26*(SUPPL. 1), S230–S242. https://doi.org/10.1016/j.landusepol.2009.09.020

Anser, M. K., Alharthi, M., Aziz, B., & Wasim, S. (2020). Impact of urbanization, economic growth, and population size on residential carbon emissions in the SAARC countries.

Clean Technologies and Environmental Policy, *22*(4), 923–936. https://doi.org/10.1007/s10098-020-01833-y

Appiah, K., Du, J., & Poku, J. (2018). Causal relationship between agricultural production and carbon dioxide emissions in selected emerging economies. Environmental Science and Pollution Research, 25(25), 24764–24777.

Badgley, C., Moghtader, J., Quintero, E., Zakem, E., Chappell, M. J., Avilés-Vázquez, K., Samulon, A., & Perfecto, I. (2007). Organic agriculture and the global food supply. *Renewable Agriculture and Food Systems, 22*(2), 86–108. https://doi.org/10.1017/S1742170507001640

Balogh, J. M. (2022). The impacts of agricultural development and trade on CO2 emissions? Evidence from the Non-European Union countries. *Environmental Science & Policy, 137*, 99–108. https://doi.org/10.1016/j.envsci.2022.08.012

Balsalobre-Lorente, D., Driha, O. M., Bekun, F. V., & Osundina, O. A. (2019). Do agricultural activities induce carbon emissions? The BRICS experience. *Environmental Science and Pollution Research, 26*(24), 25218–25234. https://doi.org/10.1007/s11356-019-05737-3

Bangake, C., & Eggoh, J. C. (2012). Pooled Mean Group estimation on international capital mobility in African countries. *Research in Economics, 66*(1), 7–17. https://doi.org/10.1016/j.rie.2011.06.001

Batmunkh, A., Nugroho, A. D., Fekete-Farkas, M., & Lakner, Z. (2022). Global Challenges and Responses: Agriculture, Economic Globalization, and Environmental Sustainability in Central Asia. *Sustainability, 14*(4), 2455. https://doi.org/10.3390/su14042455

Bouri, E., Gupta, R., Lahiani, A., & Shahbaz, M. (2018). Testing for asymmetric nonlinear short- and long-run relationships between bitcoin, aggregate commodity and gold prices. *Resources Policy, 57*, 224–235. https://doi.org/10.1016/j.resourpol.2018.03.008

Cheng, C., Ren, X., & Wang, Z. (2019). The impact of renewable energy and innovation on carbon emission: An empirical analysis for OECD countries. *Energy Procedia, 158,* 3506–3512. https://doi.org/10.1016/j.egypro.2019.01.919

Doda, B. (2014). Evidence on business cycles and CO2 emissions. *Journal of Macroeconomics, 40*, 214–227. https://doi.org/10.1016/j.jmacro.2014.01.003

Dou, Y., Zhao, J., Malik, M. N., & Dong, K. (2021). Assessing the impact of trade openness on CO2 emissions: Evidence from China-Japan-ROK FTA countries. *Journal of Environmental Management, 296,* 113241. https://doi.org/10.1016/j.jenvman.2021.113241

Du, Y., Liu, H., Huang, H., & Li, X. (2023). The carbon emission reduction effect of agricultural policy——Evidence from China. *Journal of Cleaner Production, 406*, 137005. https://doi.org/10.1016/j.jclepro.2023.137005

Fang, D., Chen, J., Wang, S., & Chen, B. (2024). Can agricultural mechanization enhance the climate resilience of food production? Evidence from China. *Applied Energy, 373,* 123928. https://doi.org/10.1016/j.apenergy.2024.123928

FAO (2020). Emissions due to agriculture. Global, regional and country trends 2000–2018. *FAOSTAT Analytical Brief Series No 18*. Rome.

Gyamfi, B. A., Onifade, S. T., Erdoğan, S., & Ali, E. B. (2023). Colligating ecological footprint and economic globalization after COP21: Insights from agricultural value-added and natural resources rents in the E7 economies. *International Journal of Sustainable Development and World Ecology, 30*(5), 500–514. https://doi.org/10.1080/13504509.2023.2166141

Haug, A. A., & Ucal, M. (2019). The role of trade and FDI for CO2 emissions in Turkey: Nonlinear relationships. *Energy Economics, 81*, 297–307. https://doi.org/10.1016/j.eneco.2019.04.006

Huang, S., Ghazali, S., Azadi, H., Movahhed Moghaddam, S., Viira, A. H., Janečková, K., Sklenička, P., Lopez-Carr, D., Köhl, M., & Kurban, A. (2023). Contribution of agricultural land conversion to global GHG emissions: A meta-analysis. *Science of The Total Environment, 876,* 162269. https://doi.org/10.1016/j.scitotenv.2023.162269

International Energy Agency (IEA). (2023). *CO2 emissions in 2023: The changing landscape of global emissions.*

IPCC. (2021). Climate Change 2021: *The Physical Science Basis.* Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

Jiang, Y., Zhang, X., & Wang, W. (2023). Environmental challenges and agricultural sustainability in SCO countries: A critical review. *Environmental Science & Policy, 137*(2), 55–63.

Kennet, M., & Heinemann, V. (2006). *Green Economics: Beyond supply and demand to meeting people's needs.* Green Economics Institute.

Khan, M. A., Tahir, A., Khurshid, N., ul Husnain, M. I., Ahmed, M., & Boughanmi, H. (2020). Economic effects of climate change-induced loss of agricultural production by 2050: A case study of Pakistan. *Sustainability, 12*(3), 1216. https://doi.org/10.3390/su12031216

Khan, Z., Ali, S., Umar, M., Kirikkaleli, D., & Jiao, Z. (2020). Consumption-based carbon emissions and international trade in G7 countries: The role of Environmental innovation and renewable energy. *Science of The Total Environment, 730*, 138945.

Khurshid, N., Khurshid, J., Shakoor, U., & Ali, K. (2022). Asymmetric effect of agriculture value added on CO2 emission: Does globalization and energy consumption matter for Pakistan. *Frontiers in Energy Research, 10*, 1053234. https://doi.org/10.3389/fenrg.2022.1053234

Koondhar, M. A., Udemba, E. N., Cheng, Y., Khan, Z. A., Batool, M., & Kong, R. (2021). Asymmetric causality among carbon emission from agriculture, energy consumption, fertilizer, and cereal food production—a nonlinear analysis for Pakistan. *Sustainable Energy Technologies and Assessments, 45*, 101099. https://doi.org/10.1016/j.seta.2021.101099

Liu, X., Zhang, S., & Bae, J. (2017). The impact of renewable energy and agriculture on carbon dioxide emissions: Investigating the environmental Kuznets curve in four selected ASEAN countries. *Journal of Cleaner Production, 164*, 1239-1247. https://doi.org/10.1016/j.jclepro.2017.07.086

Lynch, J, Cain, M., Frame, D., & Pierrehumbert, R. (2021). Agriculture's Contribution to Climate Change and Role in Mitigation Is Distinct from Predominantly Fossil CO_2-Emitting Sectors. *Frontiers in Sustainable Food Systems, 4*, 518039. https://doi.org/10.3389/fsufs.2020.518039

Martinez-Alier, J. (1995). The Environment as a Luxury Good or "Too Poor to be Green"? *Ecological Economics, 13*(1), 1-10. https://doi.org/10.1016/0921-8009(94)00062-Z

Mendonça, A. K. de S., de Andrade Conradi Barni, G., Moro, M. F., Bornia, A. C., Kupek, E., & Fernandes, L. (2020). Hierarchical modeling of the 50 largest economies to verify the impact of GDP, population and renewable energy generation in CO2 emissions. *Sustainable Production and Consumption, 22*, 58–67. https://doi.org/10.1016/j.spc.2020.02.001

Omri, A., Nguyen, D. K., & Rault, C. (2014). Causal interactions between CO2 emissions, FDI, and economic growth: Evidence from dynamic simultaneous-equation models. *Economic Modelling, 42*, 382–389. https://doi.org/10.1016/j.econmod.2014.07.026

Pesaran, M. H., Shin, Y., & Smith, R. J. (2001). Bounds testing approaches to the analysis of level relationships. *Journal of Applied Econometrics, 16*(3), 289-326.

Rahman, M. M., & Velayutham, E. (2020). Renewable and non-renewable energy consumption-economic growth nexus: New evidence from South Asia. *Renewable Energy, 147*(1), 399–408. https://doi.org/10.1016/j.renene.2019.09.007

Rehman, A., Ma, H., Khan, M. K., Khan, S. U., Murshed, M., Ahmad, F., & Mahmood, H. (2022). The asymmetric effects of crops productivity, agricultural land utilization, and fertilizer consumption on carbon emissions: revisiting the carbonization-agricultural activity nexus in Nepal. *Environmental Science and Pollution Research, 29*(26), 39827–39837. https://doi.org/10.1007/s11356-022-18994-6

Reuters. (2023). *Top CO2 emitting countries in 2023*.

Salisu, A. A., & Isah, K. O. (2017). Revisiting the oil price and stock market nexus: A nonlinear Panel ARDL approach. *Economic Modelling, 66*, 258–271. https://doi.org/10.1016/j.econmod.2017.07.010

Shabbir Alam, M., Duraisamy, P., Bakkar Siddik, A., Murshed, M., Mahmood, H., Palanisamy, M., & Kirikkaleli, D. (2023). The impacts of globalization, renewable energy, and agriculture on CO2 emissions in India: Contextual evidence using a novel composite carbon emission-related atmospheric quality index. *Gondwana Research, 119*, 384–401. https://doi.org/10.1016/j.gr.2023.04.005

Stern, D. I. (2004). The Rise and Fall of the Environmental Kuznets Curve. *World Development, 32*(8), 1419–1439. https://doi.org/10.1016/j.worlddev.2004.03.004

Taheripour, F., Hertel, T. W., & Tyner, W. E. (2011). Implications of biofuels mandates for the global livestock industry: A computable general equilibrium analysis. *Agricultural Economics, 42*(3), 325–342. https://doi.org/10.1111/j.1574-0862.2010.00517.x

Tan, S. S., & Kuebbing, S. E. (2023). A synthesis of the effect of regenerative agriculture on soil carbon sequestration in Southeast Asian croplands. *Agriculture, Ecosystems & Environment, 349*, 108450. https://doi.org/10.1016/j.agee.2023.108450

Tang, C. F., & Tan, B. W. (2015). The impact of energy consumption, income and foreign direct investment on carbon dioxide emissions in Vietnam. *Energy, 79*(C), 447–454. https://doi.org/10.1016/j.energy.2014.11.033

Choudhury, T., Kayani, U. N., Gul, A., Haider, S. A., & Ahmad, S. (2023). Carbon emissions, environmental distortions, and impact on growth. *Energy Economics*, *126*, 107040. https://doi.org/10.1016/j.eneco.2023.107040

Ullah, S., Ahmad, W., Majeed, M.T., & Sohail, S. (2021). Asymmetric effects of premature deagriculturalization on economic growth and CO_2 emissions: fresh evidence from Pakistan. *Environmental Science and Pollution Research, 28*, 66772–66786. https://doi.org/10.1007/s11356-021-15077-w

Vasichenko, K., Khan, I., & Wang, Z. (2020). Symmetric and asymmetric effect of energy consumption and CO 2 intensity on environmental quality: using nonlinear and asymmetric approach. *Environmental Science and Pollution Research, 27*, 32809-32819. https://doi.org/10.1007/s11356-020-09263-5

Vision IAS. (2024). *Shanghai Cooperation Organization: Current Affairs.*

Waheed, R., Chang, D., Sarwar, S., & Chen, W. (2018). Forest, agriculture, renewable energy, and CO2 emission. *Journal of Cleaner Production, 172*, 4231–4238. https://doi.org/10.1016/j.jclepro.2017.10.287

Yang, Z., Shao, S., Yang, L., & Liu, J. (2017). Differentiated effects of diversified technological sources on energy-saving technological progress: Empirical evidence from China's industrial sectors. *Renewable and Sustainable Energy Reviews, 72*, 1379–1388. https://doi.org/10.1016/j.rser.2016.11.072

Zhou, X., Zhang, M., Zhou, M., & Zhou, M. (2017). A comparative study on decoupling relationship and influence factors between China's regional economic development and industrial energy–related carbon emissions. *Journal of Cleaner Production, 142*, 783–800. https://doi.org/10.1016/j.jclepro.2016.09.115