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The Effect of Value Addition by Sectors On Carbon Dioxide, Methane, And Nitrous Oxide Emissions in South Asia

C. Lasantha K. Nawarathna

Department of Social Statistics, University of Sri Jayewardenepura, Sri Lanka.

Abstract:
This study examines the impact of sectoral value addition on greenhouse gas (GHG) emissions, carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) in six South Asian countries—Bangladesh, Bhutan, India, Nepal, Pakistan, and Sri Lanka—from 1990 to 2020. Grounded in the Environmental Kuznets Curve (EKC) hypothesis, the research uses panel Autoregressive Distributed Lag (ARDL) models to analyze short- and long-term dynamics between economic growth, sectoral activities, and emissions. Results indicate a U-shaped relationship for CO_2 emissions, diverging from the traditional EKC, where economic growth initially reduces emissions but later exacerbates them. The EKC hypothesis is weakly supported for CH_4, while N_2O emissions show no clear income-driven trajectory. Sectorally, manufacturing consistently drives higher emissions across all GHGs, while agriculture and services demonstrate emission-reducing effects in the long run. Industrial value addition reveals mixed impacts, decreasing CH_4 and N_2O but contributing to short-term CO_2 spikes. Bidirectional causality between GDP and emissions highlights the interdependence of economic growth and environmental outcomes. The findings stress the critical role of sector-specific policies, advocating green manufacturing technologies, sustainable agricultural practices, and an expanded service sector. Regional heterogeneity requires tailored strategies, such as Bhutan's renewable energy focus and India's fertilizer management reforms. By integrating climate objectives into economic planning, South Asia can balance developmental aspirations with ecological sustainability, aligning with global frameworks such as the Sustainable Development Goals (SDGs) and the Paris Agreement.

Keywords: Greenhouse gas emissions, Sectoral value addition, Environmental Kuznets Curve, South Asia, Panel ARDL analysis.

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1. Introduction

1.1 Background of the Study

In recent decades, the global community has seen a significant rise in greenhouse gas (GHG) emissions, mainly driven by economic growth, industrialization, and population expansion. This escalating environmental crisis has garnered widespread attention as levels of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) continue to increase, contributing to global warming, biodiversity loss, and more severe weather events (Intergovernmental Panel on Climate Change [IPCC], 2021). While much of the focus has been on developed nations, South Asia, home to nearly one-quarter of the global population, has emerged as a crucial focal point in climate change and sustainable development discussions.

With nearly 2 billion people, South Asia is highly vulnerable to the impacts of climate change, including rising temperatures, erratic monsoons, and rising sea levels. Even though the region has experienced rapid economic growth, averaging 6% annually since 2000, this advancement has led to increased emissions, positioning South Asia as a significant contributor to global greenhouse gas emissions. Tackling these challenges is essential for both regional sustainability and global climate initiatives.

The region includes Bangladesh, Bhutan, India, Nepal, Pakistan, and Sri Lanka, each having distinct economies but facing shared developmental challenges. These countries have transitioned from agriculture to manufacturing and services, often at the expense of environmental sustainability. Economic growth has increased fossil fuel use, urbanization, deforestation, and heightened emissions.

The Environmental Kuznets Curve (EKC) suggests an inverted U-shaped relationship between economic growth and environmental degradation, where emissions initially increase but later decline with rising income levels. However, its relevance to South Asia is debated due to ongoing reliance on fossil fuels and weak regulations. Most studies focus on CO_2 emissions while often neglecting methane and nitrous oxide, which significantly contribute to global warming. Research gaps in sectoral disparities hinder comprehensive policy development.

Different sectors contribute to environmental degradation in various ways. Agriculture significantly emits methane and nitrous oxide through livestock and fertilizers. Manufacturing releases considerable CO_2 due to outdated machinery and energy inefficiency. The service sector typically has a lower footprint, particularly as economies shift toward digitalization and low-carbon growth. Structural transformations from agriculture to industry and services influence emission patterns.

In South Asia, agriculture employs over 50% of the workforce and contributes 18% to GDP; however, it continues to be a significant source of emissions. Industrialization, driven by manufacturing, has led to increased urbanization and energy consumption, worsening CO_2 emissions. The service sector, which accounts for 53% of GDP, is less carbon-intensive but requires further environmental impact studies. Given these varying impacts, it is crucial to examine sectoral value addition, the contribution of individual sectors to national GDP, and their relationship with GHG emissions. Understanding each sector's long-run and short-run effects on CO_2, CH_4, and N_2O is essential for developing effective, evidence-based environmental and economic policies in South Asia. However, empirical research in this area remains limited, particularly in panel studies that investigate multiple countries over extended periods.

Therefore, this study examines how sectoral value addition influences GHG emissions across six South Asian countries from 1990 to 2020. The focus is on three primary gases: CO_2, CH_4, and N_2O, which are analyzed using a panel Autoregressive Distributed Lag (ARDL) model within the EKC framework. This approach allows for exploring both short-run dynamics and long-term equilibrium relationships among emissions, GDP, and sectoral value addition, contributing to a deeper understanding of economic-environmental connections in the region.

1.2 Research Problem and Objectives

Despite South Asia's increasing prominence in climate discussions, research remains limited on how sectoral value addition, including agriculture, industry, manufacturing, and services, impacts specific GHG emissions. Most studies narrowly focus on CO_2 or aggregate emissions, often neglecting the distinct drivers of CH_4 (e.g., agriculture) and N_2O (e.g., fertilizers) (Ravishankara et al., 2009; Tian et al., 2020). Furthermore, the Environmental Kuznets Curve (EKC) hypothesis remains underexplored in the region, with conflicting results largely stemming from methodological inconsistencies and inadequate data (Shahbaz et al., 2013; Dogan & Turkekul, 2016). Environmental degradation in South Asia continues to intensify, driven by rapid economic growth, rising energy consumption, and significant land use changes. The expansion of sectors such as manufacturing and construction has been directly linked to increasing emissions. However, there is a notable lack of empirical evidence on the sector-specific drivers of emissions within the region. While the EKC hypothesis has been widely tested globally, few studies have rigorously examined its applicability across multiple GHGs in South Asia, primarily focusing on sectoral disaggregation.

A critical gap in the literature exists due to the lack of empirical studies examining how value-added activities in agriculture, industry, manufacturing, and services affect emissions. Most existing research aggregates sectoral activities into GDP or focuses on single-country analyses, which fail to capture regional trends and interdependencies (Narayan & Narayan, 2010; Shahbaz et al., 2012). Furthermore, the intricate interactions between sectoral structures and environmental outcomes have not been thoroughly analyzed using advanced dynamic econometric models, such as panel ARDL. These models, which address cross-country heterogeneity and accommodate short-term fluctuations alongside long-term relationships, present significant potential for filling these gaps (Pesaran et al., 1999).

This study addresses these gaps by posing the following research questions:

Does the Environmental Kuznets Curve (EKC) hypothesis hold for South Asia's CO_2, CH_4, and N_2O emissions?

What is the long-term relationship between sectoral value addition and GHG emissions?

How do short-run sectoral fluctuations affect emissions across South Asian countries?

Are there bidirectional or unidirectional causal relationships between sectoral value-added activities and emissions?

Accordingly, the main objectives of the study are:

To assess the validity of the EKC hypothesis for CO_2, CH_4, and N_2O emissions in South Asia.

To quantify the effects of agriculture, industry, manufacturing, and services value addition on emissions over time.

To examine short-run and long-run dynamics using panel ARDL models.

To explore the causality between sectoral value addition and GHG emissions using Dumitrescu-Hurlin tests.

1.3 Significance of the Study

This research has significant theoretical, methodological, and practical implications. Theoretically, it enhances the Environmental Kuznets Curve (EKC) framework by integrating sectoral variables and multiple greenhouse gases (GHGs), addressing critiques regarding its oversimplification (Stern, 2004; Dinda, 2004). Methodologically, it utilizes advanced second-generation panel ARDL techniques to account for cross-sectional dependence and mixed-order integration, ensuring greater robustness compared to earlier studies (Pesaran et al., 1999; Westerlund, 2007). Practically, the findings provide actionable insights for policymakers by identifying high-emission sectors, enabling targeted interventions. For example, mitigating CH_4 emissions may necessitate agricultural reforms, while reducing CO_2 emissions could require industrial decarbonization (IPCC, 2021). Additionally, the study supports regional climate strategies such as Nepal's National Adaptation Plan and India's National Action Plan on Climate Change by offering empirical evidence for sector-specific mitigation efforts (Dhakal, 2009).

The research aligns with Sustainable Development Goals (SDGs), specifically SDG 7 (Affordable and Clean Energy), SDG 9 (Industry, Innovation, and Infrastructure), and SDG 13 (Climate Action) (UN, 2015). It is particularly relevant for South Asia, one of the world's most populous and climate-vulnerable regions, providing a comprehensive multi-country emissions analysis. By emphasizing sectoral value addition, the study delivers detailed insights into the economic activities that drive emissions, assisting policymakers in prioritizing interventions. The ARDL method further enhances statistical reliability by addressing non-stationary variables, cointegration, and heterogeneity among countries (Westerlund, 2007; Pesaran et al., 1999).

From a theoretical perspective, this research advances the literature by testing the EKC hypothesis across multiple pollutants and sectors, challenging the notion that economic growth inherently leads to environmental improvements. Empirically, it emphasizes how sector-specific strategies, such as promoting clean manufacturing, sustainable agriculture, and expanding the service sector, can shape environmental outcomes (Dogan et al., 2020; Bhattacharya & Wolde-Rufael, 2015). From a policy standpoint, the findings guide the design of targeted environmental policies aligned with the developmental priorities of South Asian countries. Given the diversity within these economies, the study's country-specific insights advocate for tailored strategies rather than generic, one-size-fits-all solutions.

Furthermore, the findings can inform regional organizations such as SAARC and multilateral institutions in developing collaborative action plans for sustainable development in South Asia. By aligning with the United Nations SDGs, particularly SDG 13 (Climate Action), SDG 9 (Industry, Innovation, and Infrastructure), and SDG 8

(Decent Work and Economic Growth), the research emphasizes that economic development must be environmentally sustainable and socially inclusive. 1.4 Methodology Overview

1.4 Methodology Overview

A comprehensive quantitative methodology based on the Environmental Kuznets Curve (EKC) hypothesis is employed to achieve the study's objectives. This research examines annual panel data from 1990 to 2020 for six South Asian countries: Bangladesh, Bhutan, India, Nepal, Pakistan, and Sri Lanka. The dataset includes 240 observations per variable, providing sufficient variation to effectively capture both short- and long-term dynamics.

The study focuses on dependent variables such as per capita emissions of CO_2, CH_4, and N_2O, all expressed in their natural logarithmic forms. The primary independent variable is log-transformed GDP per capita, which includes its square to rigorously test the EKC hypothesis. Additionally, sectoral value-added indicators—agriculture (AFFVA), industry (IVD), manufacturing (MVD), and services (SVD)—are log-transformed and included to evaluate their influence on emissions.

The analytical framework utilizes the Autoregressive Distributed Lag (ARDL) approach in a panel data context. This method is particularly suitable for the study as it accommodates variables integrated at different orders (I(0) and I(1)) and estimates short-term as well as long-term relationships (Pesaran et al., 1999; Banerjee et al., 1998). The Pooled Mean Group (PMG) estimator captures country-specific short-term dynamics while assuming a shared long-term equilibrium relationship.

Before estimation, a series of diagnostic tests are conducted to ensure the robustness of the ARDL model. These include cross-sectional dependence tests (Pesaran, 2004), unit root tests (CIPS and CADF), and Westerlund (2007) cointegration tests. These tests confirm that the ARDL model's assumptions are satisfied. Furthermore, Granger causality is examined using the Dumitrescu-Hurlin test to determine the direction of influence between sectoral value-added components and emissions. This methodology allows the study to capture both immediate (short-term) responses and lasting (long-term) trends, offering in-depth insights into the economic-environmental relationship in South Asia.

1.5 Structure of the Study

This manuscript is organized into six main sections:

Section 1: Introduction – Outlines the background, research problem, objectives, significance, and an overview of the methodology. Section 2: Literature Review – Summarizes theoretical and empirical studies on economic growth, sectoral value addition, and GHG emissions, focusing on the EKC hypothesis and the South Asian context. Section 3: Methodology – Describes the dataset, variables, econometric techniques, and the theoretical framework that supports the analysis. Section 4: Analysis – Presents the empirical results of the ARDL models and causality tests, discussing the findings for each gas (CO_2, CH_4, and N_2O). Section 5: Summary, Conclusions, and Recommendations – Highlights key findings, policy implications, and directions for future research.

2. Literature Review

Understanding the intricate relationship between economic activities and environmental degradation has garnered significant attention over the past few decades. This literature review examines existing empirical and theoretical studies related to greenhouse gas (GHG) emissions, particularly carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), within the context of sectoral value addition and the Environmental Kuznets Curve (EKC) hypothesis. The review is organized under the following subtopics:

2.1 The Environmental Kuznets Curve (EKC) Hypothesis

The EKC hypothesis suggests that environmental degradation initially increases with economic growth but eventually declines after reaching a certain income level (Grossman & Krueger, 1991; Stern, 2004). This inverted U-shaped relationship has been examined in various contexts, including CO_2 emissions (Dinda, 2004; Apergis & Payne, 2010), methane emissions (Shahbaz et al., 2013), and nitrous oxide emissions (Ravishankara et al., 2009).

Empirical evidence supporting the EKC hypothesis is mixed. Studies such as Narayan and Narayan (2010) and Al-Mulali and Ozturk (2015) confirm its validity for CO_2 emissions in several developing countries. However, others argue that the EKC may not hold uniformly across all pollutants or regions (Stern, 2004; Dogan & Seker, 2016). In South Asia, the application of the EKC has demonstrated context-specific outcomes, influenced by sectoral dynamics and policy interventions (Bhattacharya & Wolde-Rufael, 2015).

2.2 Sectoral Value Addition and Emissions

Economic sectors contribute differently to GHG emissions. Agriculture is a significant source of CH_4 and N_2O due to livestock farming and fertilizer use (EPA, 2021; FAO, 2020). Studies by Davidson (2009) and Tian et al. (2020) emphasize the impact of agricultural practices on long-term N_2O trends. Manufacturing, with its reliance on fossil fuels and energy-intensive processes, significantly contributes to CO_2 emissions (Wang et al., 2016; Zoundi, 2017).

The industrial sector has a mixed impact. While industrial value-added activities often contribute to pollution in the short run, long-term effects may be mitigated through technological advancements and cleaner production methods (Apergis & Payne, 2010; Dogan et al., 2020). The services sector, on the other hand, is generally associated with lower emissions and regarded as a cleaner alternative for economic growth (Salahuddin et al., 2018).

2.3 Empirical Studies on CO_2 Emissions

Numerous studies have examined the determinants of CO_2 emissions using both time-series and panel data. For instance, Shahbaz et al. (2013) found a significant relationship between GDP, energy use, and CO_2 emissions in South Asia. Narayan and Narayan (2010) conducted a panel analysis for developing countries and confirmed the EKC hypothesis.

Sectoral analyses by Al-Mulali and Ozturk (2015) and Dogan and Seker (2016) highlight the significant impact of manufacturing on CO_2 emissions. These studies emphasize the importance of transitioning to renewable energy and low-carbon technologies. In the context of South Asia, research by Dhakal (2009) and the World Bank (2022) offers country-specific insights into the sources and patterns of emissions.

2.4 Empirical Studies on CH_4 and N_2O Emissions

Methane and nitrous oxide have received less empirical attention than CO_2, even though they are more potent regarding their global warming potential (IPCC, 2021). Ravishankara et al. (2009) highlighted the challenges in reducing N_2O emissions due to its connection with agricultural and industrial chemical processes. Tian et al. (2020) examined fertilizer management and its influence on N_2O emissions.

In terms of CH_4, livestock management and rice cultivation are the primary contributors (FAO, 2020; EPA, 2021). Bhattacharya and Wolde-Rufael (2015) and Dinda (2004) have demonstrated that methane emissions are sensitive to income levels and agricultural practices. Dogan and Turkekul (2016) suggest that technological advancements in agriculture can reduce methane emissions.

2.5 Methodologies for Analyzing Emission Dynamics

Various econometric techniques have examined the relationship between economic activities and emissions. Panel data models like ARDL (Autoregressive Distributed Lag) are favored as they address mixed orders of integration and cointegration among variables (Pesaran et al., 1999; Westerlund, 2007). The Pooled Mean Group (PMG) estimator handles heterogeneous short-run dynamics and homogeneous long-run relationships, making it ideal for multi-country studies (Pesaran et al., 1999).

Causality analysis is often conducted using tests such as Dumitrescu-Hurlin Granger causality, which identifies the direction of influence among variables (Dumitrescu & Hurlin, 2012). These tools allow researchers to determine whether emissions drive economic activity or vice versa, an important aspect of policy design.

2.6 South Asia's Environmental and Economic Context

South Asia presents a unique case due to its rapid population growth, urbanization, and reliance on agriculture and traditional industries. While the region contributes modestly to global emissions per capita, the aggregate emissions are significant due to the large population (IPCC, 2021). Studies by Dhakal (2009) and the World Bank (2022) reveal that the region's economic structure, energy mix, and policy environment influence its emission patterns.

Sector-specific studies highlight that manufacturing in India and Pakistan is a significant source of CO_2, while rice cultivation in Bangladesh and Nepal contributes to CH_4 emissions. With its focus on hydropower, Bhutan presents a low-emission development model (Reay et al., 2012). These varied contexts require differentiated policy approaches.

2.7 Policy Implications from Existing Literature

Literature underscores the importance of targeted, sector-specific policies for reducing emissions. For manufacturing, promoting cleaner technologies and enforcing stricter regulations is essential (Wang et al., 2016; Zoundi, 2017). In agriculture, climate-smart practices such as improved irrigation and fertilizer management can reduce CH_4 and N_2O (FAO, 2020). The service sector's expansion provides an environmentally friendly growth path, primarily through digitalization and green services (Salahuddin et al., 2018). Policymakers are urged to integrate climate goals into national development strategies, aligning with global frameworks like the Paris Agreement and Sustainable Development Goals (SDGs).

2.8 Gaps in Literature

Despite the growing interest, several gaps remain. Few studies provide a comparative analysis of CO_2, CH_4, and N_2O emissions simultaneously, particularly in South Asia. Additionally, the role of sectoral value addition in influencing emissions is underexplored. Most research either focuses on aggregate GDP or employs single-country data.

Moreover, existing studies often overlook the short-run versus long-run dynamics essential for understanding the temporal effects of sectoral changes. Additionally, there is a lack of comprehensive causality analyses linking sectoral activities to emissions.

This review summarizes key theoretical and empirical contributions to the EKC hypothesis and sectoral impacts on emissions. The literature suggests that although economic growth influences emissions, the sectoral composition is critical in shaping environmental outcomes. The EKC hypothesis is context-dependent, and applying it to South Asia necessitates careful empirical validation.

Further research is necessary to close the gaps identified, particularly by employing robust methodologies such as panel ARDL and incorporating multiple GHGs. This study addresses these gaps by analyzing the impact of sectoral value addition on CO_2, CH_4, and N_2O emissions in South Asia, providing a comprehensive and policy-relevant perspective.

3. Methodology

3.1 Research Design and Framework

This study examines the influence of sectoral value addition on carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) emissions in South Asia, utilizing the Environmental Kuznets Curve (EKC) hypothesis. The EKC suggests an inverted U-shaped relationship between economic growth and environmental degradation, where emissions initially increase with rising income levels but eventually decline after reaching a critical threshold (Grossman & Krueger, 1991). Three distinct Autoregressive Distributed Lag (ARDL) models were developed for each emission type to evaluate this hypothesis and the sector-specific impacts. The ARDL methodology is particularly effective for assessing cointegration and capturing both short- and long-term dynamics in datasets with variables integrated at different orders (I(0) or I(1)) (Pesaran et al., 1999). It addresses endogeneity concerns and accommodates heterogeneous coefficients across cross-sectional units (Pesaran & Smith, 1995).

This section details the methodological framework used to assess the relationship between sectoral value addition and environmental degradation in South Asia, focusing on three greenhouse gases: CO_2, CH_4, and N_2O. The empirical approach is grounded in the EKC hypothesis and employs panel ARDL techniques. The methodology encompasses several econometric steps, including variable selection, panel data diagnostics, unit root testing, cointegration analysis, and ARDL model estimation.

3.2 Data and Variables

The study uses annual panel data from 1990 to 2020 for six South Asian countries: Bangladesh, Bhutan, India, Nepal, Pakistan, and Sri Lanka, totaling 240 observations per variable. Data was sourced from the World Development Indicators (WDI, 2022) and Our World in Data. The dependent variables include per capita emissions of CO_2, CH_4, and N_2O, which are all transformed into natural logarithms ($LNCO_2$, $LNCH_4$, LNN_2O) for normalization of distributions. The independent variables consist of GDP per capita (LNGDP) and its square ($LNGDP^2$) to address the Environmental Kuznets Curve (EKC) effect, along with contributions from sectoral value-added: agriculture (LNAFFVA), industry (LNIVD), manufacturing (LNMVD), and services (LNSVD), all of which are log-transformed (Table 1).

Table 1: Study of Variables and Data Sources

Label	Variable	Definition	Unit	**Source**
CO2	Carbon dioxide emission	Annual CO2 emissions, including land-use change, per capita	Metric tons	WDI (2022)
CH4	Per-capita methane emissions	Per-capita methane emissions in CO2 equivalents	Metric tons	Our World in Data
N2O	Per-capita nitrous oxide emissions	Per-capita nitrous oxide emissions in CO2 equivalents	Metric tons	Our World in Data
GDP	Gross Domestic Product (per capita)	Gross domestic product divided by midyear population (Constant 2015 US$)	US$	WDI (2022)
AFFVA	Agriculture, forestry, and fishing, value added	Agriculture, forestry, and fishing, value added (% of GDP)	%	WDI (2022)
IVD	Industry value added	Industry (including construction), value added (% of GDP)	%	WDI (2022)
MVD	Manufacturing, value added	Manufacturing, value added (% of GDP)	%	WDI (2022)
SVD	Services, value added	Services, value added (% of GDP)	%	WDI (2022)

Source: Created by the Author

Dependent Variables:

The dependent variables focus on three primary greenhouse gases:

Carbon dioxide emissions (CO_2): Measured in metric tons per capita, including emissions from land-use changes, sourced from WDI (2022).

Methane emissions (CH_4): Expressed in metric tons per capita in CO_2 equivalents, obtained from Our World in Data.

Nitrous oxide emissions (N_2O): Also measured in metric tons per capita in CO_2 equivalents, sourced from Our World in Data.

Independent Variables:

The primary explanatory variable is per capita GDP in constant 2015 US dollars. To capture the hypothesized inverted-U shape of the EKC, the square of GDP (GDP^2) is included.

Sectoral value-added variables include:

Agriculture, forestry, and fishing value added (AFFVA): As a percentage of GDP.

Industry value added (IVD): This includes construction and is expressed as a percentage of GDP.

Manufacturing value added (MVD): A subset of IVD, represented as a percentage of GDP.

Services value added (SVD): Represented as a percentage of GDP.
All variables are converted into their natural logarithmic forms (e.g., $LNCO_2$, LNGDP) to reduce heteroscedasticity and allow coefficients to be interpreted as elasticities.

3.3 Theoretical Framework: EKC Hypothesis

The EKC hypothesis proposes a non-linear relationship between environmental degradation and economic growth. In its typical form, environmental degradation initially worsens with economic growth, reaches a peak, and improves as income rises further (Grossman & Krueger, 1995). This concept is based on the idea that early economic growth involves resource-intensive and polluting activities. At the same time, higher income levels allow for investments in cleaner technologies and stricter environmental regulations.
The extended EKC model used in this study incorporates sectoral composition variables to capture the structural transformation of economies over time (Dinda, 2004). The model specification is as follows:

$$LNEMISSIONS_{it} = \beta_0 + \beta_1 LNGDPit + \beta_2 LN\ GDP2it + \beta_3 LNAFFVAit + \beta_4 LNIVDit + \beta_5 LNMVDit + \beta_6 LNSVDit + \varepsilon_{it} \quad \text{Eq (1)}$$

where EMISSIONS represents CO_2, CH_4, or N_2O for country i at time t. The ARDL(p, q) structure allows lagged dependent and independent variables to capture dynamic effects (Pesaran & Shin, 1999):

$$\Delta LNEMISSIONS_{it} = \phi_i\left(LNEMISSIONS_{i,t-1} - \beta_i' X_{it}\right) + \sum_{j=1}^{p-1} \alpha_j \Delta LNEMISSIONS_{i,t-1} + \delta_i' \Delta X_{i,t-j} + \lambda ECM_{i,t-i} + \mu_{it} \quad \text{Eq (2)}$$

Here, X denotes independent variables, ECM is the error correction term, and λ measures the speed of adjustment to long-run equilibrium.

3.4 Pre-Estimation Diagnostics

3.4.1 Cross-Sectional Dependence:

To explore the interconnections among South Asian economies, both Pesaran's (2004) CD test and the Breusch-Pagan LM test were utilized. These tests revealed significant cross-sectional dependence, as demonstrated in Tables 3 and 4. This finding underscores the need for second-generation unit root tests to adequately address these dependencies.

3.4.2 Unit Root Tests:

According to Pesaran (2007), the CADF and CIPS tests indicated that the variables were non-stationary at their levels but achieved stationarity upon the first difference (Table 4). This outcome satisfies the ARDL model's requirement for mixed integration, where variables can be integrated of order zero or one, denoted as I(0)/I(1).

3.4.3 Cointegration:

Westerlund's (2007) cointegration test confirmed the existence of long-term relationships within the CO_2 and N_2O models (Table 5). Utilizing the PMG estimator, the ARDL models highlighted significant long-term coefficients. Notably, a U-shaped relationship between LNGDP and $LNGDP^2$ was identified in the CO_2 model, challenging the Environmental Kuznets Curve (EKC) hypothesis (Table 6).

3.4.4 Panel Data Diagnostic Tests

Descriptive Statistics:
The descriptive statistics in Table 2 revealed moderate variability and acceptable levels of skewness and kurtosis. However, the Jarque-Bera test indicated non-normality in some variables, showing the need for robust econometric methods to ensure accurate analysis.
Cross-Sectional Dependence:
The Breusch-Pagan LM, Pesaran's scaled LM, and Pesaran CD tests (Table 3) all demonstrated significant cross-sectional dependence at the 1% significance level. This supports the use of second-generation panel techniques to manage these dependencies effectively.
Panel Unit Root Tests:
The stationarity tests, specifically the CADF and CIPS, confirmed that the variables were integrated of order one, I(1), achieving stationarity at first differences (Table 4). This result facilitates the subsequent cointegration analysis.

Cointegration Analysis:
Westerlund's (2007) panel cointegration test identified stable long-term equilibrium relationships for the CO_2, CH_4, and N_2O models (Table 5). The rejection of the null hypothesis at the 1% or 5% significance level validated the application of panel ARDL models for estimating long-run and short-run dynamics.

3.5 Post-Estimation Analysis

Error Correction:
The analysis of the error correction term (COINTEQ01) across Tables 6, 8, and 10 reveals significant negative coefficients. This result strongly supports the system's convergence towards its long-run equilibrium, indicating that deviations from equilibrium are adjusted over time.
Causality:
Using the Dumitrescu-Hurlin (2012) panel causality tests (reported in Tables 12–14), the study uncovers bidirectional causality between GDP and CO_2 emissions. Additionally, unidirectional causal relationships are observed from sectoral activities to emissions, emphasizing the influence of specific economic sectors on environmental outcomes.

3.6 Panel ARDL Model Estimation:

Given the mixed order of integration (I(0) and I(1)) and the confirmed cointegration among variables, the study employs the Pooled Mean Group (PMG) estimator within the panel ARDL framework (Pesaran, Shin, & Smith, 1999). This method effectively captures heterogeneity in short-run dynamics across countries while maintaining homogeneity in long-run coefficients.
Three ARDL models were estimated, each with CO_2, CH_4, and N_2O as dependent variables. Tables 6, 8, and 10 present the results for both long-run and short-run dynamics.
Long-Run Dynamics:
The long-run coefficients derived from all three models are consistent with the Environmental Kuznets Curve (EKC) hypothesis. Specifically:
GDP exhibits a negative coefficient, while GDP^2 is positive and statistically significant, affirming an inverted U-shaped relationship between economic growth and emissions.
Sectoral impacts on emissions are summarized as follows:
AFFVA (Agriculture, Forestry, and Fishing Value Added): Negatively correlated with emissions across all gases, suggesting that modernization in agriculture contributes to emission reductions.
IVD (Industrial Value Added): Negatively associated with CO_2 and CH_4, and strongly negative for N_2O, indicating that changes in industrial structures can significantly lower emissions.
MVD (Manufacturing Value Added): Positively linked with all greenhouse gases (GHGs), reflecting the carbon-intensive nature of manufacturing activities.
SVD (Service Value Added): Generally exhibits negative and significant coefficients, highlighting the environmental benefits of expanding the service sector.
Short-Run Dynamics:
Short-run coefficients exhibit more variability across gases and lag structures. However, all models' error correction terms (COINTEQ01) are consistently negative and statistically significant, confirming that short-term deviations from the long-run equilibrium are systematically corrected.
Tables 7, 9, and 11 provide a country-specific breakdown of short-run cointegration effects. Most countries demonstrate significant error-correction mechanisms, further validating the model's robustness.
Causality Analysis:
The Dumitrescu-Hurlin (2012) Granger causality tests were applied to explore the causal relationships among the variables. Results in Tables 12–14 reveal:
Bidirectional causality between GDP and greenhouse gas (GHG) emissions indicates a feedback loop between economic growth and environmental degradation.

Unidirectional causality from sectoral variables to emissions reinforces the role of sector-specific activities in driving emission levels.

These findings underscore the validity and relevance of the model, offering critical insights for policymakers aiming to balance economic growth with environmental sustainability.

4. Analysis

This section presents an analysis of the empirical findings from the panel Autoregressive Distributed Lag (ARDL) models that explore the relationship between sectoral value addition and greenhouse gas (GHG) emissions, specifically carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), in six South Asian countries from 1990 to 2020. The analysis adheres to the Environmental Kuznets Curve (EKC) framework. It utilizes key variables such as per capita GDP and its square and value-added components from the agriculture, industry, manufacturing, and services sectors. The results are systematically analyzed based on the provided tables and supported by established literature.

4.1 Descriptive Statistics and Variable Overview

The study utilizes panel data from six South Asian countries spanning 1990 to 2020 to examine the relationship between sectoral value addition and greenhouse gas emissions. Table 1 details the variables, which include emissions (CO_2, CH_4, N_2O), GDP per capita, and sectoral contributions from agriculture, industry, manufacturing, and services. All variables are log-transformed to address skewness and improve interpretability (Narayan & Narayan, 2010).

Table 2: Descriptive Statistics of the Study Variables

	LNCO2	LNCH4	LNN2O	LNGDP	LNAFFVA	LNIVD	LNMVD	LNSVD
Mean	0.135196	-0.058559	-0.730591	2.972791	1.370604	1.377117	1.067765	1.642867
Median	-0.037990	-0.072337	-0.726259	2.963857	1.381237	1.397955	1.145969	1.654660
Maximum	1.550676	0.270722	-0.518425	3.652798	1.762671	1.654175	1.326499	1.769659
Minimum	-0.992498	-0.261730	-1.000734	2.522712	0.860712	1.048002	0.475798	1.388991
Std. Dev.	0.574788	0.135922	0.112298	0.262005	0.175237	0.126157	0.177229	0.077118
Skewness	1.219435	0.739496	-0.334358	0.520256	-0.535419	-0.277270	-0.971300	-0.827565
Kurtosis	3.558705	2.580234	2.185029	2.706219	3.689023	3.053782	2.978429	3.567672
Jarque-Bera	62.60236	23.63621	11.11360	11.68972	16.21448	3.104078	37.74158	30.61708
Probability	0.000000	0.000007	0.003861	0.002895	0.000301	0.211816	0.000000	0.000000
Observations	240	240	240	240	240	240	240	240

Source: Author's Calculations

Table 2 presents descriptive statistics, highlighting that $LNCO_2$ has the highest variability (Standard Deviation = 0.575), indicating notable disparities in carbon emissions across countries. In contrast, $LNCH_4$ and LNN_2O exhibit lower variability, suggesting more consistent methane and nitrous oxide emission patterns. Skewness and kurtosis values confirm that most variables deviate from normal distributions, necessitating the application of robust estimation techniques (Pesaran et al., 1999).

The average logged values for CO_2, CH_4, and N_2O emissions are 0.135, -0.059, and -0.731, respectively, indicating that CO_2 is the most prevalent greenhouse gas per capita, while N_2O is the least. The mean logged GDP per capita is approximately 2.97, reflecting moderate income levels across the sampled countries. The Jarque-Bera test further confirms non-normality for most variables, except for industry value added. This deviation underscores the importance of employing robust econometric models, such as ARDL, which are well-suited for handling non-normal residuals (Pesaran & Shin, 1999; Baltagi, 2008).

3. Cross-Sectional Dependence

Table 3: Cross-Section Dependence Test

Test	**LNCO2**	**LNCH4**	**LNN2O**	**LNGDP**
Breusch-Pagan LM	150.8492*	198.0283*	122.0352*	584.9057*
Pesaran scaled LM	24.80255*	33.41625*	19.54187*	104.0501*
Bias-corrected scaled LM	24.72563*	33.33932*	19.46495*	103.9731*
Pesaran CD	-0.447686	4.737003*	4.472994*	24.18391*
	LNAFFVA	LNIVD	LNMVD	LNSVD
Breusch-Pagan LM	433.6601*	106.7416*	53.75163*	346.4430*
Pesaran scaled LM	76.43653*	16.74965*	7.075046*	60.51294*
Bias-corrected scaled LM	76.35961*	16.67272*	6.998123*	60.43601*
Pesaran CD	20.39981*	2.800217*	0.254184	12.48519*

“*” Significant at 1%

Source: Author’s Calculations

Table 3 evaluates cross-sectional dependence using the Breusch-Pagan LM, Pesaran’s scaled LM, and Pesaran’s CD tests. The findings reveal significant dependence across units for most variables, indicated by * at the 1% significance level. This suggests that shocks in one country can influence others, a common characteristic of regional environmental data where geographical, policy, and economic factors are closely interconnected (Pesaran, 2004; Chudik et al., 2011). Consequently, the use of second-generation panel methods is justified. The cross-sectional dependence (CD) tests in Tables 3 and 4 confirm notable interdependencies among South Asian economies. For example, the Pesaran CD statistic for LNGDP (24.18*) underscores strong economic integration, likely driven by regional trade and shared environmental policies (Pesaran, 2004). These dependencies highlight the need for second-generation unit root tests to mitigate the risk of spurious regression.

4. Unit Root Tests

Table 4: Results of the CADF and CIPS panel unit root tests.

	Pre-Dividend Panel				
Variable	**CADF**		**CIPS**		
	Cons	**Trend**	**Cons**	**Trend**	
LNCO2	-1.028	-1.474	-2.406**	-3.039**	
ΔLNCO2	-5.264*	-5.317*	-6.082*	-6.228*	***I (1)***
LNCH4	-0.814	-1.575	-1.493	-2.571	
Δ LNCH4	-4.072*	-2.211	-5.706*	-6.218*	***I (1)***
LNN2O	-1.731	-1.734	-1.628	-2.008	
Δ LNN2O	-3.968*	-1.729	-5.650*	-5.902	***I (1)***
LNGDP	-1.139	-1.700	-1.736	-2.174	
Δ LNGDP	-3.888*	-4.452*	-4.187*	-4.387*	***I (1)***
LNAFFVA	-1.181	-1.774	-1.649	-1.828	
Δ LNAFFVA	-3.853*	-4.066*	-5.650*	-6.200*	***I (1)***
LNIVD	-1.746	-0.333	-1.557	-2.715***	
Δ LNIVD	-4.452*	-1.973	-5.840*	-6.041*	***I (1)***
LNMVD	-1.304	-1.123	-2.031	-2.813***	
Δ LNMVD	-4.137 *	-2.265	-5.609*	-5.801*	***I (1)***
LNSVD	-1.071	-1.781	-2.272**	-2.574	
Δ LNSVD	-4.274*	-2.461	-5.733*	-5.931*	***I (1)***

“*, **, ***” Significant at 1%, 5%, and 10% respectively

Source: Author’s Calculations

Panel unit root tests (CADF and CIPS) presented in Table 4 indicate that all variables are non-stationary at levels but become stationary after first differencing, confirming they are integrated of order one, I(1). These integration properties align with the assumptions of the panel ARDL methodology, which accommodates a mix of I(0) and I(1) variables (Pesaran et al., 1999; Westerlund, 2007). The results also show that while most variables are I(1), the variable LNSVD is stationary at levels (I(0)). This mixed order of integration further supports the appropriateness of the ARDL approach, which is designed to handle variables with different integration orders (Pesaran & Shin, 1999).

5. Cointegration and Long-Run Relationships

Table 5: Results of the Westerlund (2007) cointegration test.
Ho: No cointegration

Statistic	CO2 Model	
	Value	Z-Value
Gt	-4.051*	-3.902
Ga	-16.525	-0.783
Pt	-10.397*	-4.349
Pa	-16.758**	-1.888
Statistic	CH4 Model	
Gt	-2.647	-0.531
Ga	-8.014	1.716
Pt	-8.514*	-2.771
Pa	-10.218	-0.059
Statistic	NO2 Model	
Gt	-2.977**	-1.322
Ga	-10.570	0.965
Pt	-8.102*	-2.426
Pa	-11.242	-0.345

"*, **, ***" Significant at 1%, 5%, and 10% respectively
Source: Author's Calculations

Westerlund's (2007) cointegration test results (Table 5) reject the null hypothesis of no cointegration for the CO_2 and N_2O models (G_t = -4.051* and -2.977**, respectively), confirming stable long-run relationships. In contrast, the CH_4 model provides weaker evidence of cointegration (G_a = -8.014, insignificant), suggesting that transient factors, not accounted for in the long-run framework, may influence methane emissions. These findings are consistent with studies highlighting the persistent impact of economic activities on CO_2 and N_2O emissions, while CH_4 emissions, often associated with short-term agricultural practices, exhibit a less stable relationship (Apergis & Payne, 2009).
Table 5 presents Westerlund's cointegration test applied to each GHG model. For CO_2, both Gt and Pt statistics are significant at the 1% level, indicating a robust long-run equilibrium relationship among the variables. While the CH_4 and N_2O models demonstrate cointegration, the significance levels vary. These results support the application of panel ARDL estimation to effectively capture both long- and short-run dynamics (Westerlund, 2007; Dogan & Turkekul, 2016).

6. Long-Run and Short-Run Results for CO_2 (Table 6)

6.1 Long-Run Dynamics

Table 6: Long-Run and Short-Run Panel ARDL Estimation

Dependent Variable – LNCO2

Variable	Coefficient	Std. Error	t-Statistic	Prob.*
	Long Run Equation			
LNGDP	-2.768489*	0.563085	-4.916644	0.0000
LNGDP2	0.491703*	0.099891	4.922409	0.0000
LNAFFVA	-1.828484*	0.211176	-8.658576	0.0000
LNIVD	-1.581418*	0.341049	-4.636922	0.0000
LNMVD	0.471065**	0.222342	2.118653	0.0379
LNSVD	-1.199138*	0.242034	-4.954428	0.0000
	Short Run Equation			
COINTEQ01	-0.827451*	0.267044	-3.098555	0.0029
D(LNCO2(-1))	-0.164862	0.165184	-0.998054	0.3219
D(LNCO2(-2))	-0.068412	0.113565	-0.602405	0.5490
D(LNGDP)	-64.32132***	32.84759	-1.958175	0.0544
D(LNGDP(-1))	-86.97877	85.21745	-1.020669	0.3111
D(LNGDP(-2))	-38.88885	51.93700	-0.748770	0.4567
D(LNGDP(-3))	76.01686	47.53443	1.599196	0.1146
D(LNGDP2)	10.38423***	5.222463	1.988377	0.0509
D(LNGDP2(-1))	15.39033	14.97547	1.027703	0.3078
D(LNGDP2(-2))	6.252291	8.712633	0.717612	0.4755
D(LNGDP2(-3))	-13.85490	8.755838	-1.582361	0.1183
D(LNAFFVA)	3.116259*	0.840531	3.707489	0.0004
D(LNAFFVA(-1))	3.418866**	1.497780	2.282622	0.0257
D(LNAFFVA(-2))	2.992458***	1.511499	1.979796	0.0519
D(LNAFFVA(-3))	0.984906	1.009111	0.976013	0.3326
D(LNIVD)	-2.661585	2.295071	-1.159696	0.2504
D(LNIVD(-1))	-1.290943	0.835670	-1.544800	0.1272
D(LNIVD(-2))	-1.712731**	0.854131	-2.005233	0.0490
D(LNIVD(-3))	-2.799802	2.246678	-1.246197	0.2171
D(LNMVD)	2.794696	2.027333	1.378508	0.1727
D(LNMVD(-1))	1.042895***	0.532529	1.958381	0.0544
D(LNMVD(-2))	2.069978**	0.983676	2.104330	0.0392
D(LNMVD(-3))	2.050752	1.688229	1.214736	0.2288
D(LNSVD)	2.635603	1.971476	1.336867	0.1859
D(LNSVD(-1))	4.817366***	2.665453	1.807335	0.0753
D(LNSVD(-2))	4.873895***	2.513401	1.939164	0.0568
D(LNSVD(-3))	2.706837***	1.446169	1.871730	0.0657
C	8.178855*	2.727336	2.998843	0.0038

"*, **, ***" Significant at 1%, 5%, and 10% respectively

Source: Author's Calculations

Table 6 presents the Long-Run and Short-Run Panel ARDL Estimations on CO2 emissions. The coefficients of GDP and its square are significant, with GDP showing a negative coefficient (-2.768) and GDP^2 a positive one (0.492), supporting the Environmental Kuznets Curve (EKC) hypothesis (Grossman & Krueger, 1995; Stern, 2004). This indicates that CO_2 emissions initially decrease as income rises but begin to increase after surpassing a certain income threshold. Additionally, AFFVA, IVD, and SVD exhibit significantly negative impacts on CO_2 emissions, suggesting that growth in the agriculture, general industry, and services sectors contributes to emission reductions, likely due to enhanced efficiencies or lower carbon intensity (Narayan & Narayan, 2010; Shahbaz et al., 2013). On the other hand, manufacturing value added (MVD) has a significant positive effect (0.471), highlighting manufacturing as a CO_2-intensive activity in South Asia. This aligns with existing literature, which identifies manufacturing as a primary emission driver due to reliance on fossil fuels and inefficient technologies (Zoundi, 2017; Apergis & Payne, 2010). The long-run estimates reveal a U-shaped relationship between LNGDP and $LNCO_2$ (LNGDP = -2.768*, $LNGDP^2$ = 0.491*), diverging from the traditional EKC hypothesis. This suggests that economic growth in South Asia exacerbates carbon emissions beyond a specific threshold, consistent with trends observed in rapidly industrializing regions (Stern, 2004). Sectorally, agriculture (LNAFFVA = -1.828*) and services (LNSVD = -1.199*) reduce CO_2 emissions, likely due to their lower energy intensity than the industrial sector. Conversely, manufacturing (LNMVD = 0.471**) increases emissions, reflecting its dependence on fossil fuels in production processes (Al-Mulali & Ozturk, 2015).

6.2 Short-Run Dynamics

The short-run dynamics exhibit considerable volatility and are essentially insignificant, with only a few lags showing notable effects. However, the error correction term (COINTEQ01) is negative and statistically significant at -0.827, signifying a robust adjustment speed toward the long-run equilibrium, as Banerjee et al. (1998) highlighted. This suggests that deviations from the equilibrium are corrected by approximately 82.7% annually, ensuring a rapid return to stability. Regarding short-term influences, the lagged differences of AFFVA (Agriculture, Forestry, and Fishing Value Added) and SVD (Sectoral Value Differences) demonstrate a measurable impact on emission reductions, underlining their importance in shaping short-run dynamics. Specifically, the short-term coefficient for agriculture (D(LNAFFVA) = 3.116*) indicates temporary spikes in emissions, likely driven by factors such as land-use changes or the application of fertilizers, as noted by Our World in Data (2022). These findings emphasize the interplay between agricultural activities and emission patterns in the short run.

Country-Level Short-Run Cointegration for CO_2

Table 7: Cross-sectional short-run cointegration

Dependent Variable – LNCO2

Cross section	Cointegrate Coefficient	t-stat
Bangladesh	-1.435964*	-108.6725
Bhutan	0.268354*	13.73245
India	-1.171339*	-23.65165
Nepal	-0.677488*	-20.29868
Pakistan	-1.412610*	-63.85595
Sri Lanka	-0.535660*	-49.28096

"*, **, ***" Significant at 1%, 5%, and 10% respectively

Source: Author's Calculations

Table 7 reveals notable differences in short-run cointegration dynamics among the six countries analyzed. Five countries, excluding Bhutan, display significant negative short-run cointegration coefficients, indicating a tendency to correct back to equilibrium following short-term disturbances in CO_2 levels. In contrast, Bhutan presents a positive coefficient, which suggests a divergence from equilibrium. This could be attributed to Bhutan's distinctive developmental policies or irregularities in the data. These findings highlight the diverse environmental adjustment mechanisms across nations, underscoring the complexity of global CO_2 dynamics (Levin et al., 2002; Im et al., 2003).

8. Long-Run and Short-Run Results for CH_4

Table 8: Long-Run and Short-Run Panel ARDL Estimation

Dependent Variable – LNCH4

Variable	Coefficient	Std. Error	t-Statistic	Prob.*
	Long Run Equation			
LNGDP	1.863400**	0.768051	2.426142	0.0162
LNGDP2	-0.237142**	0.119423	-1.985740	0.0486
LNAFFVA	-0.249025*	0.087101	-2.859039	0.0048
LNIVD	-0.716879*	0.210357	-3.407917	0.0008
LNMVD	0.314966*	0.109474	2.877099	0.0045
LNSVD	-0.917167*	0.210955	-4.347685	0.0000
	Short Run Equation			
COINTEQ01	-0.237647**	0.095111	-2.498621	0.0134
D(LNGDP)	2.588904	1.753698	1.476255	0.1416
D(LNGDP2)	-0.401349	0.271567	-1.477902	0.1412
D(LNAFFVA)	0.049514	0.089760	0.551625	0.5819
D(LNIVD)	0.239951***	0.138359	1.734260	0.0846
D(LNMVD)	-0.113573	0.084309	-1.347103	0.1796
D(LNSVD)	0.165663***	0.084164	1.968333	0.0506
C	-0.220166**	0.100904	-2.181940	0.0304
@TREND	-0.001628***	0.000832	-1.955617	0.0521

"*, **, ***" Significant at 1%, 5%, and 10% respectively

Source: Author's Calculations

8.1 Long-Run Dynamics

Methane (CH_4) emissions exhibit a similar Environmental Kuznets Curve (EKC) pattern (Table 8), with GDP positively and GDP^2 negatively affecting emissions at a 5% significance level. This supports the EKC hypothesis for CH_4 (Stern, 2004; Dinda, 2004). All sectoral variables significantly influence CH_4 emissions. Agricultural value-added (AFFVA) and industrial value-added (IVD) have negative impacts, whereas manufacturing value-added (MVD) increases methane emissions, highlighting the environmentally detrimental effects of manufacturing activities. Conversely, service value-added (SVD) reduces CH_4 emissions, reinforcing the role of a service-oriented economy in mitigating emissions (Dogan & Seker, 2016; Bhattacharya & Wolde-Rufael, 2015).

The long-run EKC for CH_4 is confirmed (LNGDP = 1.863, $LNGDP^2$ = -0.237), indicating that methane emissions peak at a certain GDP threshold. Agriculture (LNAFFVA = -0.249*) and services (LNSVD = -0.917*) contribute to reducing methane emissions, while manufacturing (LNMVD = 0.315*) increases them. The latter aligns with waste generation in manufacturing sectors (World Bank, 2022). The error correction term (COINTEQ01 = -0.237**) indicates a slower adjustment rate of 23.7%, compared to CO_2. This reflects the complex sources of methane emissions, such as rice paddies and livestock, which are less responsive to economic policies (IPCC, 2019).

8.2 Short-Run Dynamics

In the short run, GDP and its square are insignificant, implying that CH_4 emissions respond to income changes only in the long term. The error correction term remains significant (-0.237), though weaker than the CO_2 model. Industrial value-added (IVD) and service value-added (SVD) positively influence CH_4 emissions in the short run, possibly due to temporary industrial expansions that lead to increased methane emissions (Soytas & Sari, 2009).

9. Country-Level Short-Run Cointegration for CH_4

Table 9: Cross-sectional short-run cointegration

Dependent Variable – LNCH4

Cross section	Cointegrate Coefficient	t-stat
Bangladesh	-0.252049*	-37.16707
Bhutan	-0.306476*	-49.48069
India	-0.109637*	-27.68876
Nepal	0.022839*	16.48156
Pakistan	-0.129888*	-13.21868
Sri Lanka	-0.650669*	-34.78044

"*, **, ***" Significant at 1%, 5%, and 10% respectively

Source: Author's Calculations

Table 9 highlights the presence of significant correction coefficients across all analyzed countries. Notably, Nepal stands out with a positive correction coefficient, suggesting a divergence from the expected trends. This divergence is consistent with the characteristics of Nepal's agricultural economy, where methane emissions predominantly stem from livestock farming and rice cultivation. These sources may not conform to typical methane emission patterns observed in other regions (EPA, 2021).

10. Long-Run and Short-Run Results for N_2O

Table 10: Long-Run and Short-Run Panel ARDL Estimation

Dependent Variable – LNN2O

Variable	Coefficient	Std. Error	t-Statistic	Prob.*
	Long Run Equation			
LNGDP	4.557676*	1.183574	3.850772	0.0002
LNGDP2	-0.554810*	0.168565	-3.291380	0.0014
LNAFFVA	-0.210689*	0.074087	-2.843811	0.0054
LNIVD	-2.425641*	0.328198	-7.390795	0.0000
LNMVD	1.050361*	0.138647	7.575813	0.0000
LNSVD	-0.344323***	0.184406	-1.867207	0.0647
	Short Run Equation			
COINTEQ01	-0.363342***	0.201654	-1.801808	0.0745
D(LNN2O(-1))	0.016859	0.189558	0.088938	0.9293
D(LNGDP)	-11.15269	7.403726	-1.506362	0.1351
D(LNGDP(-1))	4.453980	4.864890	0.915536	0.3621
D(LNGDP(-2))	1.538326	2.980818	0.516075	0.6069
D(LNGDP2)	1.734478	1.128732	1.536660	0.1275
D(LNGDP2(-1))	-0.753220	0.828156	-0.909514	0.3652
D(LNGDP2(-2))	-0.340376	0.512426	-0.664243	0.5080
D(LNAFFVA)	0.125554	0.259384	0.484048	0.6294
D(LNAFFVA(-1))	0.177658	0.107816	1.647789	0.1025
D(LNAFFVA(-2))	0.137771***	0.072880	1.890391	0.0615
D(LNIVD)	0.566074**	0.260965	2.169158	0.0324
D(LNIVD(-1))	0.710583***	0.360782	1.969564	0.0516
D(LNIVD(-2))	0.373819***	0.200116	1.868013	0.0646
D(LNMVD)	-0.346602***	0.176154	-1.967606	0.0518
D(LNMVD(-1))	-0.320151	0.194388	-1.646975	0.1026
D(LNMVD(-2))	-0.085432	0.077053	-1.108745	0.2701
D(LNSVD)	0.008002	0.154151	0.051910	0.9587

D(LNSVD(-1))	0.023608	0.312270	0.075602	0.9399
D(LNSVD(-2))	0.042852	0.137900	0.310751	0.7566
C	-2.281213***	1.289066	-1.769664	0.0798
@TREND	-0.004844	0.003220	-1.504535	0.1355

"*, **, ***" Significant at 1%, 5%, and 10% respectively

Source: Author's Calculations

10.1 Long-Run Dynamics

The analysis of N_2O emissions reveal a pattern consistent with the Environmental Kuznets Curve (EKC) hypothesis (Table 10). In this context, Gross Domestic Product (GDP) positively affects emissions, while the square of GDP (GDP^2) has an adverse effect, both statistically significant at the 1% level. Agricultural value-added (AFFVA) and services value-added (SVD) are associated with reductions in N_2O emissions, suggesting that these sectors contribute to more sustainable practices. Conversely, manufacturing value-added (MVD) is linked to increased emissions, likely due to industrial activities. Industrial value-added (IVD) demonstrates the most substantial negative impact on emissions, highlighting the importance of industrial restructuring in mitigating nitrous oxide emissions, as noted by Wang et al. (2016). However, the EKC is not fully evident for N_2O, as the coefficient for $LNGDP^2$ is negative but not statistically significant. Reductions in emissions are also observed in the industrial sector (LNIVD = -2.425*) and agriculture (LNAFFVA = -0.210*), possibly due to improvements in efficiency. On the other hand, the manufacturing sector (LNMVD = 1.050*) contributes to higher N_2O emissions, potentially driven by chemical production processes, as Ravishankara et al. (2009) discussed. The relatively weak error correction term (COINTEQ01 = -0.363***) suggests a slow pace of adjustment in reducing nitrous oxide emissions, often linked to long-term soil management practices, as highlighted by Tian et al. (2020).

10.2 Short-Run Dynamics (Table 11)

Table 11: Cross-sectional short-run cointegration

Dependent Variable – LNN2O

Cross section	Cointegrate Coefficient	t-stat
Bangladesh	-0.135824*	-36.15161
Bhutan	-0.102610*	-40.26713
India	0.014458*	13.60453
Nepal	-0.079881*	-215.9522
Pakistan	-0.609148*	-32.20178
Sri Lanka	-1.267047*	-130.5930

"*, **, ***" Significant at 1%, 5%, and 10% respectively

Source: Author's Calculations

In the short run, Table 11 highlights that the dynamics of N_2O emissions reveal fewer significant coefficients. Some lagged variables of IVD and MVD show significance, but with changing signs, indicating variability in their impact over time. The error correction term (-0.363) is only weakly significant at the 10% level, suggesting a slower adjustment process than the CO_2 and CH_4 emissions models.

11. Country-Level Short-Run Cointegration for N_2O

An examination of country-level short-run cointegration for N_2O emissions shows that all countries, except India, have negative and significant error correction terms. This suggests that most countries are moving towards equilibrium in their N_2O emission dynamics. However, India presents a unique case with a positive coefficient, indicating persistent divergence in N_2O emissions. This divergence may be attributed to high fertilizer use and emission-intensive agricultural practices, as reported by the Food and Agriculture Organization (FAO, 2020).

12. Granger Causality Analysis

Table 12: Pairwise Dumitrescu Hurlin Panel Causality Tests of the CO2 model

Variables	LNCO2	LNGDP	LNAFFVA	LNMVD	LNIVD	LNSVD
LNCO2		4.63670*	1.48564	2.10771**	4.16196*	2.10771**
LNGDP	7.72602*		5.82556*	5.27482*	5.83766*	2.29391
LNAFFVA	6.13420*	2.76025		3.92048***	6.89785*	1.08737
LNMVD	3.19785*	3.03254	2.91106		2.97857	5.17121*
LNIVD	1.72144***	1.61673	3.08625	2.54875		1.08585
LNSVD	3.19785*	2.91834	2.82765	2.38581	4.61030*	

"*, **, ***" Significant at 1%, 5%, and 10% respectively

Source: Author's Calculations

Table 13: Pairwise Dumitrescu Hurlin Panel Causality Tests of the CH4 model

Variables	LNCH4	LNGDP	LNAFFVA	LNMVD	LNIVD	LNSVD
LNCH4		4.62474*	4.06857**	3.04118	3.06450	7.31669*
LNGDP	4.87454*		5.82556*	5.27482*	5.83766*	2.51413
LNAFFVA	2.92819	2.76025		3.92048	6.89785*	1.08737
LNMVD	2.83976	3.03254	2.91106		2.97857	2.38581
LNIVD	3.16887	1.61673	3.08625	2.54875		1.08585
LNSVD	3.15907	2.93250	2.82765	5.17121*	4.61030*	

"*, **, ***" Significant at 1%, 5%, and 10% respectively

Source: Author's Calculations

Table 14: Pairwise Dumitrescu Hurlin Panel Causality Tests of the N2O model

Variables	LNN2O	LNGDP	LNAFFVA	LNMVD	LNIVD	LNSVD
LNN2O		3.23020	4.72889*	2.49977	4.41994**	3.26183
LNGDP	4.51808**		5.82556*	5.27482*	5.83766*	2.51413
LNAFFVA	3.71201***	2.76025		3.92048**	6.89785*	1.08737
LNMVD	3.01568	3.03254	2.91106		2.54875	2.38581
LNIVD	3.14054	1.61673	3.08625	2.97857		1.08585
LNSVD	4.96894*	2.93250	2.82765	5.17121*	4.61030*	

"*, **, ***" Significant at 1%, 5%, and 10% respectively

Source: Author's Calculations

The Dumitrescu-Hurlin panel causality tests provide robust evidence of bidirectional causality between GDP and emissions of CO_2, CH_4, and N_2O, aligning with the Environmental Kuznets Curve (EKC) hypothesis. This indicates that economic growth is influenced by emissions and influenced by emissions. Moreover, both Manufacturing Value-Added (MVD) and Industrial Value-Added (IVD) demonstrate strong causal relationships with all types of emissions, underlining their pivotal role in shaping emission trends (Dogan et al., 2020).

For CO_2 emissions, the Dumitrescu-Hurlin test (Table 12) confirms bidirectional causality between GDP and CO_2 (LNGDP ↔ $LNCO_2$). This reflects feedback loops where economic growth leads to increased emissions, affecting economic performance through regulatory costs and environmental constraints (Dinda, 2004).

In the case of CH_4 emissions (Table 13), the analysis reveals unidirectional causality from the service sector's value-added (LNSVD) to methane emissions ($LNCH_4$), with a significant coefficient of 7.316*. This finding highlights the critical role of waste management practices in the service sector for mitigating methane emissions.

For N_2O emissions (Table 14), the results show bidirectional causality between agriculture-related value-added (LNAFFVA) and nitrous oxide emissions (LNN_2O), with a significant coefficient of 4.728*. This underscores agriculture's dual role as both a significant source and a potential sink for nitrous oxide emissions, reflecting its complex interaction with environmental dynamics (Davidson, 2009).

These findings emphasize the necessity of designing emission control policies that are both sector-specific and tailored to the unique circumstances of individual countries. Such an approach would help to maximize the dual benefits of environmental sustainability and economic growth (Salahuddin et al., 2018).

5. Summary, Conclusions, and Recommendations

5.1 Summary of the Study

This study explores the intricate relationship between sectoral economic activities and greenhouse gas (GHG) emissions across six South Asian nations: Bangladesh, Bhutan, India, Nepal, Pakistan, and Sri Lanka. The focus is on three major types of emissions, carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), within the framework of the Environmental Kuznets Curve (EKC) hypothesis. By analyzing panel data from 1990 to 2020 and employing the Autoregressive Distributed Lag (ARDL) modeling technique, the research examines both long-term and short-term impacts of economic growth and structural changes in various sectors on environmental quality. The study incorporates key explanatory variables, such as per capita gross domestic product (GDP), the squared term of per capita GDP (to capture non-linear relationships), and sectoral value added from agriculture (AFFVA), industry (IVD), manufacturing (MVD), and services (SVD). The dependent variables are the per capita emissions of CO_2, CH_4, and N_2O, all expressed in their natural logarithmic forms to ensure better interpretability and consistency in the analysis.

Comprehensive diagnostic tests confirm the existence of cross-sectional dependence among the countries and indicate non-stationarity of the data at the level, with all variables becoming stationary after first differencing. Cointegration tests further validate the presence of long-run equilibrium relationships among the variables, justifying the application of panel ARDL models. Separate models are developed and analyzed for each emission type, offering detailed insights into the dynamics of sectoral contributions.

The findings strongly align with the EKC hypothesis, demonstrating an inverted U-shaped relationship between economic growth and emissions. Manufacturing significantly drives increased emissions, while agriculture and services generally exhibit emission-reducing effects. The industrial sector displays a dual nature, often contributing to emission reductions in the long run but occasionally increasing them in the short term. Additionally, Granger causality tests reveal a bidirectional causality between GDP and emissions, as well as between sectoral value addition and emissions, highlighting the interconnectedness between economic structures and environmental outcomes. This underscores the critical role of sector-specific policy interventions in achieving sustainable development goals.

5.2 Conclusions

5.2.1 Confirmation of the EKC Hypothesis

The study provides compelling evidence supporting the Environmental Kuznets Curve (EKC) hypothesis across three major greenhouse gas (GHG) emissions: CO_2, CH_4, and N_2O. The findings reveal that gross domestic product (GDP) negatively impacts emissions in the long term, while the squared term of GDP (GDP^2) shows a positive influence. This dynamic indicates that emissions initially decline with rising income levels but begin to increase after surpassing a certain economic growth threshold. Such an inverted U-shaped trajectory mirrors the economic transition from agriculture-based activities to industrialization and eventually to a service-dominated economy, as previously outlined by Grossman and Krueger (1995), Dinda (2004), and Stern (2004).

CO_2 Emissions:

The analysis identifies a U-shaped relationship between GDP and CO_2 emissions, deviating from the traditional EKC hypothesis. Specifically, the positive coefficient for $LNGDP^2$ (0.491*) in Table 6 suggests that economic growth in South Asia intensifies carbon emissions once a particular income threshold is reached. This pattern is consistent with findings from rapidly industrializing economies, where industrial expansion and energy consumption lead to increased carbon footprints (Stern, 2004).

CH_4 Emissions:

A weak EKC relationship is observed for methane emissions. Emissions peak at a specific GDP level, as indicated by the negative coefficient for $LNGDP^2$ (-0.237**) in Table 8. This outcome aligns with studies linking methane emissions to transitional agricultural practices, such as livestock farming and rice cultivation, which are prominent during economic development phases (IPCC, 2019).

N_2O Emissions:

No significant EKC relationship is found for nitrous oxide emissions. Although the coefficient for $LNGDP^2$ (-0.554*) in Table 10 is negative, it is statistically insignificant. This highlights the multifaceted nature of nitrous oxide drivers, including fertilizer use, industrial processes, and waste management practices, which may not follow a clear income-related trajectory (Ravishankara et al., 2009). This result resonates with other empirical studies conducted in developing and emerging economies (Narayan & Narayan, 2010; Shahbaz et al., 2012; Dogan & Turkekul, 2016).

In the context of South Asia, the EKC hypothesis suggests that while rising income levels may initially contribute to a temporary reduction in emissions, achieving long-term environmental sustainability necessitates proactive measures. These include targeted sectoral reforms, stricter regulatory frameworks, and clean technology adoption to mitigate the adverse environmental impacts of economic growth.

5.2.2 Sectoral Impacts on Emissions

Manufacturing Value Added (MVD):

Manufacturing consistently shows a significant increase in greenhouse gas (GHG) emissions, particularly carbon dioxide (CO_2) and nitrous oxide (N_2O), across all three models. This trend highlights the carbon-intensive nature of manufacturing in South Asia, driven by the region’s dependence on fossil fuels, outdated production technologies, and weak enforcement of environmental regulations (Zoundi, 2017; Wang et al., 2016).

Agriculture, Forestry, and Fishing Value Added (AFFVA):

The agriculture sector demonstrates a long-term negative impact on emissions, suggesting that modern and sustainable farming practices can enhance environmental sustainability. However, short-term results show variability, likely due to seasonal factors and diverse agricultural practices across countries (EPA, 2021; FAO, 2020). In the long term, agriculture significantly reduces CO_2 emissions (-1.828*) and N_2O emissions (-0.210*). Conversely, short-term emissions increase (D(LNAFFVA) = 3.116*), likely due to land-use changes and transitional factors (FAO, 2021).

Industry Value Added (IVD):

The industrial sector exhibits mixed impacts on emissions. While it significantly reduces methane (CH_4) and nitrous oxide (N_2O) emissions in the long term, it occasionally contributes to higher emissions in the short term. This pattern reflects gradual technological progress and adoption of cleaner production processes over time, contrasted with short-term industrial expansions or economic shocks (Bhattacharya & Wolde-Rufael, 2015; Soytas & Sari, 2009). Long-term analysis indicates a notable reduction in N_2O emissions (-2.425*), as shown in Table 10. This highlights the energy-intensive nature of manufacturing and the gradual shift toward cleaner technologies (Al-Mulali & Ozturk, 2015).

Services Value Added (SVD):

The service sector emerges as the most environmentally sustainable, consistently reducing long-term CO_2, CH_4, and N_2O emissions. This supports the notion that transitioning to a knowledge- and service-based economy can decouple economic growth from environmental degradation (Dogan & Seker, 2016; Stern, 2004). The service sector demonstrates its lower carbon footprint by reducing emissions across all GHGs: CO_2 (-1.199*), CH_4 (-0.917*), and others, as highlighted in Tables 6 and 8. This underscores its role as a pivotal driver of sustainable economic development (World Bank, 2022).

5.2.3 Short-Run Versus Long-Run Adjustments

The error correction terms (ECMs) across all three ARDL models are negative and statistically significant, indicating that deviations from the long-run equilibrium are gradually corrected. Among the variables, the adjustment speed is the fastest for CO_2 emissions and the slowest for N_2O emissions. This suggests that carbon dioxide emissions are more responsive to economic and structural changes than nitrous oxide emissions. This observation highlights the critical need for timely policy interventions to mitigate environmental degradation, particularly in the short term, to address the faster-reacting emissions like CO_2 (Pesaran et al., 1999; Westerlund, 2007).

5.2.4 Country-Level Heterogeneity

An analysis of country-specific data using short-run cointegration tests reveals significant heterogeneity among nations. Bhutan and Nepal display divergence in specific emission patterns, while India exhibits notable inconsistencies in N_2O dynamics. These variations emphasize that universal, one-size-fits-all policies are unlikely to be effective. Instead, national strategies should be tailored to reflect each country's unique circumstances, including resource availability, energy policies, and technological capabilities (Chudik et al., 2011; Im et al., 2003). For instance, Bhutan's positive CO_2 coefficient (0.268*, Table 7) contrasts sharply with India (-1.171*) and Pakistan (-1.412*), reflecting differing energy policy approaches (Dhakal, 2009). In the case of CH_4 emissions, Nepal's reliance on livestock (0.022*, Table 9) contrasts with Sri Lanka's reduction in emissions (-0.650*), underscoring disparities in agricultural practices across the region (Reay et al., 2012). Similarly, for N_2O emissions, Sri Lanka (-1.267*, Table 11) and Pakistan (-0.609*) exhibit high emissions due to excessive fertilizer use, highlighting the environmental challenges posed by over-reliance on chemical inputs in agriculture (Tian et al., 2020).

5.2.5 Direction of Causality

The Dumitrescu-Hurlin panel causality tests reveal bidirectional causality between economic growth and greenhouse gas (GHG) emissions, reinforcing the concept of circular causality. This dynamic indicates that economic growth influences environmental outcomes, while environmental degradation, in turn, impacts economic performance. Sectoral variables, such as motor vehicle density (MVD) and industrial value density (IVD), also demonstrate significant causal relationships with emissions, further complicating the balance between economic growth and sustainability (Dinda, 2004; Dogan et al., 2020). For example, the bidirectional causality observed between GDP and CO_2 emissions (Table 12: LNGDP $\leftrightarrow$ $LNCO_2$) illustrates a feedback loop where economic expansion drives emissions, which impose economic costs (Dinda, 2004). Additionally, the unidirectional causality from the services sector to CH_4 emissions (Table 13: LNSVD $\rightarrow$ $LNCH_4$) underscores the critical role of waste management in reducing methane emissions (IPCC, 2021).

5.2.6 Theoretical Implications

The findings challenge the universal applicability of the Environmental Kuznets Curve (EKC) hypothesis in the South Asian context. While the inverted U-shaped relationship between GDP and CH_4 emissions is weakly supported, the observed U-shaped relationship between CO_2 emissions and GDP suggests that unchecked industrialization continues to drive environmental degradation. This observation aligns with critiques of the EKC hypothesis in developing regions, where industrial growth often exacerbates ecological harm (Stern, 2004). Furthermore, the absence of an EKC relationship for N_2O emissions highlights the need for models incorporating sector-specific drivers, such as agricultural practices and industrial chemicals (Davidson, 2009). These results align with recent studies advocating multidimensional frameworks that account for the diverse pathways of emissions across sectors and regions (Poumanyvong & Kaneko, 2010).

5.3. Recommendations

5.3.1 Promote Green Manufacturing

To mitigate the environmental impact of manufacturing, policymakers should prioritize investments in cleaner production technologies, energy-efficient systems, and advanced waste management solutions. Offering incentives such as tax rebates for adopting low-emission technologies and imposing penalties on polluting processes can encourage industries to transition to sustainable practices (Apergis & Payne, 2010; Shahbaz et al., 2013).

Regional cooperation among South Asian nations can play a pivotal role in facilitating the exchange of green manufacturing technologies and establishing unified regulatory standards. Public-private partnerships (PPPs) can mobilize resources to accelerate the shift toward sustainable industrial practices. For instance, incentivizing the adoption of solar and wind energy in manufacturing processes (Table 6: LNMVD = 0.471**) can draw inspiration from Bhutan's hydropower success (Table 7) (IPCC, 2021). Additionally, implementing regionally harmonized carbon pricing mechanisms, such as carbon taxes, can help internalize the cost of emissions. This strategy is crucial for high-emitting nations like Pakistan and India (World Bank, 2022).

5.3.2 Strengthen the Service Sector

The service sector's consistently negative correlation with emissions highlights its potential as a driver of sustainable growth. South Asian economies should focus on expanding service industries such as information and communication technology, financial services, education, healthcare, and tourism (Dogan & Seker, 2016). Digitalization, in particular, can reduce emissions by minimizing transportation needs and streamlining production processes (Salahuddin et al., 2018).

To harness the environmental benefits of the service sector, governments should promote green services like eco-tourism and digital platforms, which have demonstrated emission-reduction potential (Table 6: LNSVD = -1.199*) (Narayan & Narayan, 2010). Investing in recycling infrastructure can help curb methane emissions from landfills (Table 13) (IPCC, 2019).

5.3.3 Modernize Agriculture

Although agriculture appears environmentally benign in the long term, methane emissions from livestock and rice paddies remain a pressing concern. Governments should adopt climate-smart agricultural practices, including improved irrigation techniques, alternate wetting and drying methods, and optimized fertilizer usage (FAO, 2020; EPA, 2021). Supporting smallholder farmers through training programs, subsidies for eco-friendly inputs, and enhanced market access can simultaneously improve environmental outcomes and ensure food security. Precision farming techniques can help reduce short-term spikes in nitrous oxide emissions (Table 10) by enabling targeted fertilizer application, as the FAO (2021) recommends. Additionally, promoting biogas plants to convert livestock waste into energy can address methane challenges, particularly in Nepal (Table 9) (Smith et al., 2008).

5.3.4 Transition to Sustainable Industry

The industrial sector holds significant potential for long-term emission reductions. Governments should encourage structural shifts by promoting light, green, and circular industries. Integrating energy audits, cleaner production standards, and environmental impact assessments into industrial policies can ensure a sustainable transformation of the sector (Narayan & Narayan, 2010; Dogan et al., 2020).

5.3.5 Tailor National Policies

Given individual countries' varying environmental challenges, national governments must design customized policies. For instance, Bhutan and Nepal require targeted strategies to address livestock-related emissions, while India should focus on managing nitrous oxide emissions through fertilizer subsidies and land-use regulations (Bhattacharya & Wolde-Rufael, 2015). Cross-country benchmarking and regional forums under SAARC can facilitate harmonizing environmental strategies while accommodating national differences.

5.3.6 Strengthen Environmental Governance

Effective environmental governance is essential for monitoring emissions and enforcing regulations. Governments must enhance environmental agencies' independence, funding, and technical capabilities to ensure robust oversight. Incorporating environmental impact metrics into national accounting systems can provide a solid foundation for evidence-based policymaking (Wang et al., 2016; Stern, 2004).

5.3.7 Integrate Climate Objectives into Economic Planning

Climate change mitigation efforts should be seamlessly integrated into broader economic development plans. Aligning trade policies, foreign investment frameworks, and fiscal strategies with environmental objectives is crucial. Approaches such as green budgeting, environmental fiscal reforms, and emission trading systems can ensure that fiscal policies contribute to sustainable development goals (Zoundi, 2017; Stern, 2004).

Conclusion

The U-shaped correlation between CO_2 emissions and GDP highlights an urgent call for comprehensive decarbonization policies, particularly through transitioning industries to renewable energy sources (IPCC, 2021). In the agricultural sector, the mixed environmental impacts demand sustainable practices such as precision farming, which can effectively mitigate short-term emission spikes (Smith et al., 2008). Regional disparities further underline the necessity of tailored, country-specific strategies. For instance, Bhutan has prioritized green energy, while Pakistan has focused on implementing industrial reforms to address its emission challenges.

Empirical evidence derived from three ARDL models strongly supports the Environmental Kuznets Curve (EKC) hypothesis in South Asia, emphasizing the crucial influence of sectoral value addition on emission trends:

The manufacturing sector persistently emerges as a significant contributor to higher emissions levels.

The agriculture and services sectors exhibit more environmentally friendly attributes, contributing less to emissions.

The industrial sector presents a complex picture, with its effects on emissions varying depending on the type of gases involved and the time frame considered.

Policy recommendations emphasize advancing green technologies within the manufacturing sector and promoting cleaner, sustainable practices in agriculture and services. Long-term strategies should focus on structural transformations, prioritizing low-emission sectors, and ensuring a sustainable trajectory for economic growth.

This study offers an in-depth analysis of how sectoral value addition shapes the emissions trajectory in South Asia. It rejects the applicability of a universal EKC framework and instead advocates for nuanced, sector-specific policies that align economic development with environmental sustainability. The diversity within the region necessitates customized approaches—Bhutan's green energy initiatives and Pakistan's industrial reforms serve as prime examples of such tailored strategies. As climate risks grow more severe, these findings underscore the pressing need to integrate emission reduction measures into South Asia's broader development agenda, ensuring a balance between economic progress and ecological responsibility.

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Corresponding Author: C. Lasantha K. Nawarathna, Department of Social Statistics, University of Sri Jayewardenepura, Sri Lanka.

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