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Examining the Relationship of Renewable Energy Use, Urbanization, and Industrialization in Shaping Carbon Emissions in South Asia

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ABSTRACT

This research investigates the dynamic impact of various factors including economic growth, the expansion of renewable energy sources, urbanization, industrialization, tourism, agriculture, and forestry on carbon dioxide (CO2) emissions in Pakistan, India, and Bangladesh from 1980-2022. The research centers on the three most populous nations of the three countries. To quantify the correlation between emissions and the myriad of distinct categories of drivers, national time series data annually are utilized. To ascertain the immediate and enduring consequences of emissions fluctuations, DOLS methods are used for data analysis. The results indicate that increasing levels of energy consumption, GDP per capita, tourism arrivals, agricultural activities, and industrialization are all significant long-term contributors to rising CO2 emissions in each of the three countries. However, there is some evidence that implementing sustainable agricultural practices, expanding forest cover, and increasing the output of renewable energy sources could potentially serve as mitigating factors. Based on the study's results, to reconcile the pursuit of development objectives with emission reduction, it is recommended that economic growth strategies prioritize low-carbon sectors, accelerate the adoption of renewable energy sources, promote sustainable agricultural and tourism practices, and foster regional collaboration. Integrated planning for inclusive, environmentally friendly, and sustainable growth trajectories can be enhanced by incorporating comprehensive understandings of the interplay among interconnected factors that impact emission patterns. Customized development trajectories ought to be established for Pakistan, India, and Bangladesh.

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1. Introduction

In the twenty-first century, the presence of a high concentration of greenhouse gases (GHGs), most notably carbon dioxide (CO2), is the greatest contributor to climate

change. Human activities such as the burning of fossil fuels and the destruction of forests release these greenhouse gases into the atmosphere (Raihan et al., 2021; Wang et al., 2020). They believed that continuous CO2 emissions would have a cataclysmic effect on the global ecosystem, with repercussions for all aspects of human society. It is envisaged that these effects will manifest considerably sooner rather than later. The reduction of carbon dioxide emissions and the improvement of environmental quality have emerged as global priorities for the preservation of sustainable development and the mitigation of climate change (Rahman et al., 2022; Raihan & Tuspekova, 2022a). Moreover, the United Nations has approved the Sustainable Development Goals (SDGs) for the year 2030. These goals (SDGs 7, 8, 9, and 13) emphasize the importance of renewable energy and energy efficiency, equitable and comprehensive economic growth, and technological innovation as essential components of climate change solutions.

According to Raihan et al. (2022) and Voumik, Islam, et al. (2023), increased economic activity contributes significantly to the accumulation of greenhouse gases in the form of carbon dioxide emissions. After being compiled, the findings were reported in three distinct articles. According to Raihan and Tuspekova (2022b), accelerated urbanization, industrialization, and population growth are major contributors to rising CO2 emissions. Population growth, the urbanization cycle, and rising industrialization have all contributed to the constant increase in global energy consumption, which has resulted in environmental degradation (Voumik & Sultana, 2022). Population growth, the urbanization cycle, and rising industrialization have all contributed to the escalating global energy demand. In recent years, the global trend towards higher temperatures has become more pronounced for this reason. The purpose of sustainable development is to reduce human impact on the environment by reducing carbon emissions and increasing the use of environmentally favorable production techniques and technologies. According to the findings of the Intergovernmental Panel on Climate Change (IPCC), the sudden rise in global temperature that began in the middle of the 20th century can be attributed to industrialization-related emissions. Changes in lifestyle, the structure of industries, and the nature of economic activity brought about by urbanization have an effect on the quantity of carbon dioxide released into the atmosphere.

According to Voumik and Ridwan (2023), urbanization is widely acknowledged as an essential component of global development. As a consequence of the combustion of fossil fuels, the amount of carbon emissions in the atmosphere is increasing, causing global climate change (Khan & Ali, 2022). To ensure the survival of humanity, it is essential to raise awareness of the significance of environmental protection and make it a top priority. The fundamental causes of the degradation of the natural environment are, on the one hand, the continuous advancement of technology and, on the other hand, the inefficient utilization of natural resources in the production of man-made goods. According to research, the consumption of large quantities of electricity and other forms of energy by urban residents has a negative impact on the natural environment immediately adjacent to these areas. Urban economies have the potential to have a significant impact on the natural environment primarily in two ways. Urbanization, which modifies how resources are exploited, accelerates the transition to unconventional fuels. This is one of the primary causes of the transition's rapid pace. According to Anser et al. (2021), it is very simple to achieve economies of scale and environmentally friendly technologies when urban economic development is robust. These two factors make it possible to utilized the earth's natural resources more efficiently.

South Asian nations are responsible for the vast majority of the world's continuously rising carbon emissions. Extremely high energy consumption in this region contributes to the production of carbon dioxide, a primary contributor to climate change. The majority of South Asian nations are making concerted efforts to initiate numerous energy programs, the majority of which are geared toward the production of nonrenewable energy sources. However, this results in an increase in the demand for energy, which, when coupled with the rapid urbanization that is occurring, makes it difficult to operate energy-driven facilities, as these plants require a substantial amount of space to operate correctly. According to

Javeed et al. (2021), India and Pakistan are primarily liable for environmental contamination in the region due to the substantial amount of carbon dioxide they emit into the atmosphere. According to Wang et al. (2020), South Asian forests, which are home to some of the world's most ecologically diverse ecosystems, are presently being deforested for industrialization and urbanization. Pakistan is presently experiencing the highest rate of deforestation within the SAARC region. According to the findings of Shekhawat et al. (2022), the number of people residing in metropolitan areas of the SAARC region is expected to grow by around 250 million by the year 2030. Despite the damage it causes to the natural environment, urbanization is one of the most important factors in the growth of the SAARC nations' economies (Jadoon et al., 2021). In addition, the natural resource rent, also known as NRR, is a crucial factor to consider when calculating carbon emissions and maintaining a healthy environment. In keeping with M. According to Ahmad et al. (2020), economies with access to an abundant supply of natural resources should grow more quickly than those without such access.

Pakistan is considered to be a developing nation among the nations of South Asia. Agriculture is Pakistan's most important economic sector and a significant contributor to the country's economy. However, because Pakistan's manufacturing industry is expanding at such a rapid rate, the quantity of land available for agricultural purposes is decreasing. Tourism is a major contributor, both positively and substantially, to Pakistan's foreign exchange reserves, and it is also one of the country's primary employment generators. Under the umbrella term "tourism," there are additional subcategories, such as ecotourism, adventure tourism, archaeological and historical tourism, and tourism centered on religious locations. According to Yeoman (2009), religious tourism is the practice of traveling to various places of devotion, such as mosques, tombs, and other sacred structures and locales, to achieve personal fulfillment through the experience. Pakistan is home to a large number of archaeologists and travelers due to the ancient civilizations that once flourished in the Indus Valley, such as Harappa and Mohenjo-Daro, and the Mughal influence. Ecotourism, nature tourism, and aesthetic tourism are frequently intertwined. Festivals, museums, locally crafted items, and regional cuisine are the four most essential aesthetic resources for ecotourism. Typically, the term "adventure tourism" evokes mental images of magnificent landscapes, treacherous topography, towering mountains, and other similar features. Muree, Naran, Kagan, Neelum Valley, Hunza, Kashmir, Skardu, and Gilgit are among the most prominent adventure travel destinations in Pakistan. These regions contain some of the world's most breathtaking landscapes, including glaciers, lakes, rivers, and summits. These northern regions are so stunningly attractive that they attract tourists from around the globe. In 2022, 6.1% of Pakistan's gross domestic product was attributable to the tourism industry. According to World Bank (2022), Pakistan's forest cover has decreased from 6.4% of its total land area in 1991 to 4.8% of its total land area today. Despite Pakistan's crucial function as a carbon sink, the proportion of land covered by trees has decreased since 1991. As a result, it is of the utmost significance to conduct research into the forest's potential to reduce CO2 emissions in Pakistan.

The rapid urbanization occurring in India has a negative impact on the organic character of the country's economic development. Currently, a significant portion of India's population is transitioning from rural to urban contexts. The rapid urbanization that is occurring in India has a negative effect on the country's long-term development because it has led to an increase in energy consumption and contributed to the degradation of the ecosystem. Among the factors that contribute to CO2 emissions are the consumption of energy in residential and commercial settings, the energy required by the building sector to improve infrastructures, transportation, and residential areas, and the conversion of forested land to make room for urban expansion. In addition, industrialization in India has ushered in a new era for the economy, as it accounts for nearly 30% of the country's gross domestic product (WDI, 2022). The progression of industrialization, which begins at a low level of development and advances to higher levels, is frequently accompanied by industrial revolutions and changes in energy utilization models, both of which lead to an increase in energy consumption and CO2 emissions. Beginning with a modest level of development, the progression of industrialization and industrialization advances to higher levels. Additionally,

the tourism industry makes substantial contributions to India's economy. Due to the nation's 18 million international visitors in 2019, the Globe Bank ranked it as the 29th most visited country in the globe and the most visited country in South Asia. According to the United Nations World Tourism Organization (UNWTO), the number of international tourists will reach 2 billion by 2030 (Raihan & Tuspekova, 2022a). This will result in a global revenue of two billion dollars per year. Tourism is associated with an increase in the demand for energy for transport systems, food, lodging, services and facilities, and maintenance of tourist attractions, all of which have the potential to degrade the environment (Raihan & Tuspekova, 2022b). The World Tourism Organization of the United Nations estimates that tourism accounts for approximately 5% of global emissions. According to Lenzen et al. (2018), India's tourism industry has the fourth largest carbon footprint in the globe. On the other hand, tourism-driven economic growth encourages countries to invest more in environmentally friendly and innovative emission reduction strategies. This is notably true regarding developing nations. This is particularly true for developing countries.

Bangladesh is a South Asian nation that is advancing rapidly despite its alarming population growth and worsening environmental issues. According to data from the World Bank (2022), Bangladesh's economy is expanding at the second-fastest rate in South Asia and the fifth-fastest rate globally. The expansion of Bangladesh's economy has been dependent on the country's consumption of various types of fuel. According to Oh and Bhuyan (2018), the majority of Bangladesh's energy supply is derived from carbon-rich fossil fuels. These fuels include, among others, natural gas, oil, and coal. According to World Bank (2022), 74% of Bangladesh's total energy consumption in 2014 came from fossil fuels. This expansion has been fueled by industrialization and population growth. As a direct consequence, the nation is extremely concerned about the increase in emissions, particularly those originating from the energy industry. To be aware of the numerous policy options available, it is essential to research the relationship between economic growth, increases in energy consumption, and CO2 emissions in Bangladesh. Particularly in Bangladesh, an increasing number of individuals are relocating to the country's main metropolitan centers. An estimated 37.41% of Bangladesh's population resides in urban areas and communities (Teng et al., 2021). This proportion represents 37.41% of the nation's total population. Rapid urbanization in Bangladesh poses a challenge to the country's efforts to achieve sustainable development, as it leads to an increase in energy consumption and has a negative impact on the environment. Agriculture is still Bangladesh's primary source of income. According to the World Bank (WDI, 2022), despite the fact that its share of the country's gross domestic product has decreased over time. Bangladesh is a nation undergoing development. In the past three decades, a substantial quantity of research has been conducted on the factors contributing to the degradation of the natural environment.

1.1 Research Problem

South Asia has experienced a rapid but carbon-intensive expansion as a consequence of urbanization, industrialization, and increased consumption. This development has led to an exponential increase in fossil fuel consumption and CO2 emissions. Despite the availability of options such as renewable energy and sustainable agriculture, it is difficult to anticipate and manage emission trajectories due to the complex interactions between these variables. Existing research that analyses the factors that cause South Asian emissions lacks system modeling that is both comprehensive and integrated. There are still significant knowledge deficits surrounding how multi-sector variables such as economic growth, energy transitions, tourism, and forest cover interact dynamically to affect regional carbon dioxide emissions over time. To determine the relationship between economic growth and climate vulnerability in South Asia, it is crucial to conduct research employing rigorous, quantitative analysis that integrates these multifaceted forces. The application of more complex simulation models can influence carbon mitigation policies and climate-smart planning for low-emissions, sustainable regional growth.

1.2 Objective of the Study

The main focus is to examine how economic growth, renewable energy consumption, urbanization, and industrialization impact CO2 emissions. This involves analyzing the influence of tourism, industrialization, urbanization, economic growth, agricultural productivity, renewable energy consumption, and forest area on CO2 emissions.

1.3 Contribution and Significance of the Study

This is the first study that examines the impact of tourism, industrialization, urbanization, economic growth, agriculture productivity, renewable energy consumption, and forest area on CO_2 emissions in Pakistan, India, and Bangladesh. There was no such study conducted in the past that covers Pakistan, India, and Bangladesh mutually. This cross-country systems analysis will make important contributions to the academic literature on modeling interconnected emission drivers across emerging economies. The integrated simulation model capturing interactions between key forces like economic growth, energy transitions, tourism, and land use change can provide a novel holistic methodology. The comparative lens across Pakistan, India, and Bangladesh also allows unique theoretical insights into variegated development patterns shaping emissions amidst the region's rapid growth. Extending existing empirical work often focused on individual factors, findings will advance conceptual knowledge on the complex combinations of variables influencing emissions trajectories. Dynamic scenario analysis can enhance understanding of mitigation pathways aligned with Paris Agreement commitments and sustainable development goals. Published results can spur new research questions and interdisciplinary collaborations around sustainable regional growth. Overall, this study promises to expand academic understanding of managing carbon footprints during dynamic social and economic change in South Asia.

This research holds deep policy significance for South Asia’s sustainable development pathways. The advanced integrated models quantifying how economic, energy, land use, and infrastructure dynamics interact to shape South Asia's escalating emissions trajectory will provide data-driven insights to guide climate policymaking. By revealing synergies and tradeoffs between growth, emissions, and sustainability objectives, findings can inform planning around energy, urbanization, industry, and tourism that promote climate-resilient, equitable futures across South Asia. Overall, this systems-based research will deliver critical knowledge on managing carbon impacts amidst the region’s dynamic development, spurring further work on South Asia’s contributions to planetary sustainability.

2. Literature Review

Sumaira and Siddique (2023) are tasked with investigating the relationship between industrialization and energy consumption in contaminated environments in Pakistan. This study utilized panel data from 1984 through 2016. This information was gathered with the aid of global development indicators. This study incorporated the Augmented Mean Group (AMG), the Common Correlated Effects Mean Group (CCEMG), Westerlund co-integration, and the Dumitrescu-Hurlin causality test. The findings indicate that an increase in energy consumption is one factor that contributes to the industrialization processes. In addition, the data indicate that the quality of the environment decreases by 0.41 percent for every 1 percent increase in urbanization. The findings indicate this to be the case.

Gangopadhyay et al. (2023) investigated the correlation between industrialization and CO2 emissions in Pakistan from 1995 to 2020 using World Development Indicators. Employing quintile ARDL estimation, the study found no empirical evidence supporting the notion that carbon emissions increased due to industrialization. Instead, it revealed an inverse relationship between industrial gross value added (IGVA) and CO2 emissions, suggesting a need for environmentally friendly and sustainable economic growth to meet Pakistan's sustainable development goals. Banga et al. (2023) explored the impact of

tourism development on Pakistan's economy and environment using ARDL estimation from 1971 to 2019. The study revealed a significant influence of tourist numbers and carbon dioxide emissions on the country's Gross Domestic Product (GDP). The findings suggest that an increase in both tourists and CO2 emissions could lead to a long-term decline in Pakistan's GDP, emphasizing the need for policies addressing environmental concerns in developing nations.

Voumik and Ridwan (2023) investigated the impact of foreign direct investment (FDI), industrialization, and education on CO2 emissions in Pakistan from 1972 to 2021 using ARDL analysis. While education spending showed a minor but significant influence on emissions, short-term estimates revealed positive correlations between FDI, population, industrialization, and CO2 emissions, though not statistically significant. The study underscores investing in education as a key strategy for short-term CO2 reduction, suggesting increased focus on education, research, and development to bolster Pakistan's sustainable economy.

Raihan (2023) research examined the intricate interrelationships between Pakistan's economic growth, utilization of renewable energy sources, urbanization, industrialization, tourism, agricultural productivity, forest area, and carbon emissions. For this investigation, time series data from 1990 to 2020 were collected. Every item of information was collected for each of the World Development Indicators (WDI) variables. The co-integration of the series was examined using a co-integration test, and the auto-regressive distributed lag (ARDL) Model was employed to conduct the investigation and interpret the results. According to the information at hand, Pakistan's CO2 emissions will increase by 0.16 percent, 1.25 percent, 0.06 percent, and 0.02 percent if economic growth, urbanization, industrialization, and tourism increase by one percent. These percentages depict the entirety of the country. In addition, an increase of 1% in the consumption of renewable energy, agricultural production, or forest area could potentially reduce CO2 emissions by 1.50 percentage points, 0.20 percentage points, and 3.46 percentage points, respectively. This study's findings have significant implications for public policy concerning low-carbon economies, the promotion of renewable energy sources, ecologically responsible tourism, climate-smart agriculture, and sustainable forest management. All of these variables could contribute to Pakistan's environmental sustainability by reducing the nation's overall emission levels.

Rehman et al. (2023) investigated the dynamic impact that Pakistan's industrialization and financial inclusion have had on the nation's capacity to maintain a healthy environment. Their findings were published in the journal Environment and Development Economics. In this investigation, data collected by the Panel between 2004 and 2019 were utilized. Here are the results of WDI and ES's joint data collection. Within the scope of this investigation, the system dynamic GMM estimation method was implemented. According to these findings, both FI and IZ contribute to an increase in greenhouse gas production, with IZ partially mitigating the relationship between FI and CO2 emissions. Both FI and IZ are responsible for the increase in greenhouse gas production. If Pakistan's decision-makers alter their trade policy to be more under that of emerging nations, we will be able to influence Pakistan's economy.

Pata et al. (2023) conducted research in Pakistan to determine how various factors, including trade liberalization, tourism, renewable energy, and direct foreign investment, affect CO2 emissions. For this investigation, panel data were collected from 1995 to 2018. All of the data was collected with the aid of a program known as Global Development Indicators (WDI). This investigation employed several other estimation techniques, including panel ARDL PMG testing, panel causality testing, and unit root testing, among others. All of these studies indicate that tourism and FDI are the primary contributors to the increase in CO2 emissions, whereas real income and expanding trade openness are environmentally beneficial. It is only feasible to reduce carbon emissions through the use of renewable energy sources in the short term; this practice has no long-term effect on environmental quality. It is suggested that Pakistan increase its utilization of renewable

energy sources to create a sustainable environment. In addition, it is suggested that Pakistan reduce its tourism industry's reliance on fossil fuels. Finally, it is suggested that Pakistan promote economic growth.

Ali et al. (2023) examined the effects of financial inclusion (FI), agricultural innovation (AI), trade (TR), and forest rent (FR) on carbon dioxide emissions (CO2), economic growth (Y), and ecological footprint (EFP) in Pakistan. This study analyzed time series data from 1970 to 2017 using symmetric and asymmetric co-integration techniques. The information was collected from a variety of sources, including the World Development Indicators (WDI) and the Sustainable Development Goals (SDG). Throughout this study, both linear and nonlinear auto-regressive distributive lag (NARDL) techniques were employed. The empirical findings indicate that a non-linear analysis of the model used to predict economic growth reveals that agricultural innovations and CO2 emissions have asymmetric ties with economic development, whereas the forest does not. This conclusion was reached after it was discovered that the forest lacks such connections. Increasing green mechanization in agriculture, a method that reduces the use of hazardous agricultural pesticides is suggested as a policy proposal to assist Pakistan in maintaining both its environment and economy.

Using time series data from 1990 to 2018, Guang-Wen et al. (2023) analyzed the effects of globalization, alternative energy sources, and agricultural practices on CO2 emissions in Pakistan. Every item of information used in the authors' study was obtained from the World Bank and the World Development Indicators. To accomplish the objective of this investigation, the Dynamic Auto-regressive Distributed Lag (DARDL) regression technique was used. The consolidation of these empirical findings reveals that the primary long-term drivers of air pollution are globalization (particularly via economic and social channels), agricultural output growth, and higher population densities. In addition, it has been demonstrated that the relationship between the use of renewable energy sources and the condition of the atmosphere changes over time and takes the form of an inverted U. It has been demonstrated that this is the case. To reduce the overall birth rate, Pakistan should therefore make it a top priority to implement birth control measures.

Chen (2023) researched to investigate the impact of tourism policies, economic variables, and environmental factors on the viability of tourism development in Pakistan. For this investigation, time series data from 1990 to 2020 were collected. The World Development Indicators (WDI) served as the source for the information used in this investigation. This investigation utilized the nonlinear auto-regressive distributed lagged (NARDL) estimation technique. According to these findings, there is a positive relationship between the long-term sustainability of tourism growth and variables including GDP, national income, tourism policy related to tourist arrival, and FDI. This conclusion is supported by the fact that each of these factors contributes to the expansion of tourism. According to the findings, emissions of carbon dioxide (CO2), greenhouse gases (GHG), and nitrous oxide (NOx) have a negative relationship with the expansion sustainability of the tourism industry. This was determined to be true. These findings provide guidelines for implementing the regulations for the sustainable growth of tourism in Pakistan through the cultivation of favorable economic and environmental conditions as well as effective tourist policies. This can be accomplished by cultivating favorable economic and environmental conditions.

Voumik, Nafi, et al. (2023) conducted a study to determine the influence of Pakistan's tourism industry, GDP per capita, renewable energy sources, energy intensity, urbanization, and population growth on the country's natural resources. From 1995 to 2019, this study relied on the panel for its data collection. All of the data was collected with the aid of a program known as Global Development Indicators (WDI). Within the purview of this study, the cross-sectionally auto-regressive distributed lag (CS-ARDL) technique was employed. According to these findings, expanding population, rising energy consumption, and expanding economic development all contribute to the increase in CO2 emissions. Tourism and the use of renewable energy are the only activities that have the potential to

help lower CO2 emissions. Electric vehicles and bicycles are examples of low-carbon modes of transportation that politicians and tour operators may promote to encourage more people to use electric vehicles and to reduce the amount of carbon dioxide emitted during bicycle excursions. Carbon dioxide (CO2) emissions can be reduced by constructing eco-lodges and hotels that responsibly manage their water and waste, utilize renewable energy sources, and are constructed in an environmentally responsible manner.

Raihan et al. (2023) investigated the dynamic effects of Pakistan's economic growth, energy consumption, tourism, and agricultural production on the nation's carbon dioxide emissions. To analyze time series data covering the years 1990 and 2019, the Dynamic Ordinary Least Squares (DOLS) approach was deployed. These empirical data demonstrate that economic growth, the use of fossil fuels for energy, and tourism all contribute to the deterioration of Pakistan's environment through their cumulative CO2 emissions. On the other hand, an increase in the proportion of renewable energy sources and an increase in agricultural output can contribute to a reduction in the quantity of carbon dioxide emitted into the atmosphere. To accomplish a low-carbon economy, authorities must give serious consideration to a variety of concepts, such as expanding the use of renewable energy, green tourism, and climate-smart agriculture. If these measures were implemented, Pakistan's environment would be more sustainable and its emissions would decrease.

2.1 Gap of the Literature

It has been analyzed from the literature that an increase in carbon emission is dangerous both for living things and society. We reviewed research on a large scale and have seen that some researchers conducted research purely on the environment and some saw it on the growth in the economy of the country. Most of the studies are the individual ones of a country. This is the only study that not only covers both the environmental and social issues but is also conducted in three countries i.e., Pakistan, India & Bangladesh.

3. Data and Methodology

3.1 Description of the Variables

CO2 is the dependent variable while GDP, renewable energy use, urbanization, forest area, industrialization, international tourism, and agriculture productivity are the independent variables. The data set of all variables was taken from the WDI. For the analysis, the study used the log form of CO2, GDP, TR, and FA. The explanation is given in the table as follows:

Table 1
Variables Description

Code	Variables Full Name	Measurements	Source
CO2	CO2 emissions	Kilo tons	WDI
GDP	Gross Domestic Product	Constant LCU	WDI
RNE	Renewable energy use	% of total final energy consumption	WDI
URB	Urbanization	% of urban population	WDI
IND	Industrialization	value added (annual % growth)	WDI
TR	International tourism	Number of arrivals	WDI
AP	Agriculture productivity	value added (% of GDP)	WDI
FA	Forest area	sq. km	WDI

3.2 Model

The functional relationship of variables is given under the following model:

$$CO2 = f(GDP, RNE, URB, IND, TR, AP, FA) \quad (1)$$

$$CO_{2it} = \alpha_0 + \alpha_1 GDP_{it} + \alpha_2 RNE_{it} + \alpha_3 URBt + \alpha_4 IND_{it} + \alpha_5 TR_{it} + \alpha_6 AP_{it} + \alpha_7 FA_{it} + \varepsilon \quad (2)$$

3.3 Estimation Technique

Dynamic Ordinary Least Squares (DOLS) method can handle the complexities of non-stationary time series data when discussing cointegration. This is the method's area of expertise. DOLS is a statistical technique utilized most frequently in econometrics and time series analysis. Its primary objective is to describe and quantify correlations between variables that exhibit long-term co-movements while allowing for short-term fluctuations. This is achieved by combining the use of difference transformations and dynamic modeling. DOLS transforms the data into a format that is suitable for linear regression analysis to capture the dynamic nature of the data-generating process. This is achieved by differentiating nonstationary data and incorporating lagged variables into the analysis. In addition, the DOLS model includes an error correction mechanism, which is necessary for understanding how variables respond to deviations from the relationships that comprise their long-term equilibrium. Due to the prevalence of cointegration in economic and financial research, this method is a crucial tool for analyzing and modeling the interrelationships that exist in these disciplines.

4. Results and Discussion

Table 2 displays the outcomes of multiple normality tests (skewness, kurtosis, jarque bera, and probability) as well as the results of the summary procedure among variables. From 1980 to 2022, 129 samples of South Asian annual data were used for every single indicator. Kurtosis was used to evaluate if the series was light tailed or heavy-tailed when compared to a normal distribution when the estimate of Skewness is practically zero, indicating that all of the variables are moreover regularly distributed. Furthermore, the Jarque Bera probability calculation concludes that all the variables are normal. The table 3 presents the results of the correlation analysis for the linear relationship between the variables.

Table 2
Descriptive Statistics of the Variables

	CO2	RNE	IND	AP	GDP	TR	URB	FA
Mean	5.15	50.35	6.13	22.87	13.29	5.89	1.75	4.87
Median	5.00	51.54	6.51	22.97	13.28	5.70	1.76	4.61
Maximum	6.39	73.16	17.37	34.70	14.17	7.25	1.96	5.86
Minimum	4.03	24.75	-5.75	11.63	12.55	5.02	1.54	3.16
Std. Dev.	0.71	12.25	3.46	5.57	0.40	0.60	0.14	0.70
Skewness	0.17	-0.05	-0.68	0.09	0.29	0.62	-0.22	0.47
Kurtosis	1.95	2.46	4.92	2.37	2.55	2.42	1.85	1.67
Jarque-Bera	6.56	1.58	29.65	2.34	2.93	10.03	8.15	14.30
Probability	0.04	0.45	0.00	0.31	0.23	0.01	0.02	0.00
Sum	664.91	6494.55	790.95	2950.16	1715.04	759.46	225.74	628.47
Sum Sq. Dev.	64.94	19197.94	1536.30	3973.32	20.75	46.83	2.34	63.26
Observations	129	129	129	129	129	129	129	129

Table 3
Correlation Analysis

	CO2	RNE	IND	AP	GDP	TR	URB	FA
CO2	1.00							
RNE	-0.56	1.00						
IND	-0.09	-0.08	1.00					
AP	-0.33	0.90	-0.18	1.00				
GDP	0.92	-0.78	-0.10	-0.60	1.00			
TR	0.96	-0.45	-0.16	-0.22	0.88	1.00		
URB	0.62	-0.59	-0.20	-0.35	0.70	0.61	1.00	
FA	0.90	-0.25	-0.10	-0.05	0.73	0.89	0.31	1.00

The unit root test was used to show the viability of employing the DOLS estimation model rather than merely co-integration by ensuring that no parameter exceeded the integration order. Table 4 displays the results of the unit root test using the ADF, DFGLS, and PP tests. The DOLS method is superior to conventional co-integration methods since the variable remains stationary at combined levels either in level or first deference integration.

Table 4
Unit Root Test

	ADF Test		DFGLS Test		PP Test	
Variables	**I(0)**	**I(1)**	**I(0)**	**I(1)**	**I(0)**	**I(1)**
CO2	-1.55	-11.067	-1.146	-11.104	-1.599	-11.067
	(0.5045)	(0.000)*	(0.25)	(0.000)*	(0.4797)	(0.000)*
RNE	-1.116	-10.53	-0.776	-10.55	-1.473	-10.56
	(0.71)	(0.000)*	(0.44)	(0.000)*	(0.544)	(0.000)*
IND	-8.591	-14.643	-8.572	-3.555	-8.78	-41.26
	(0.000)*	(0.000)*	(0.000)*	(0.000)*	(0.000)*	(0.0001)*
AP	-1.687	-11.125	0.0212	-9.714	-1.933	-11.176
	(0.44)	(0.000)*	(0.98)	(0.000)*	(0.316)	(0.0123)**
GDP	-2.163	-11.11	-2.092	-11.043	-2.257	-11.11
	(0.2211)	(0.000)*	(0.038)**	(0.000)	(0.188)	(0.000)*
TR	-1.671	-11.018	-1.316	-11.055	-1.721	-11.018
	(0.444)	(0.000)*	(0.191)	(0.000)*	(0.418)	(0.000)*
URB	-1.585	-10.781	-1.529	-10.824	-1.737	-10.7956
	(0.488)	(0.000)*	(0.129)	(0.000)*	(0.410)	(0.000)*
FA	-1.511	-16.106	-0.558	-16.135	-2.004	-16.315
	(0.5251)	(0.000)*	(0.0001)*	(0.000)*	(0.285)	(0.000)*

Note: *,** and *** denote significance level at 1%, 5% and 10% respectively. standard errors are in parentheses.

Table 5
Cointegration with ARDL bound Test

F-Bounds Test		Null Hypothesis: No levels of relationship		
Test Statistic	**Value**	**Significance**	**I(0)**	**I(1)**
			Asymptotic: n=1000	
F-statistic	11.63298	10%	1.85	2.85
K	8	5%	2.11	3.15
		2.50%	2.33	3.42
		1%	2.62	3.77

The analysis reveals significant relationships between various factors and carbon dioxide (CO2) emissions. The study employs the Dynamic Ordinary Least Squares (DOLS) method in econometrics, focusing on variables such as gross domestic product (GDP) squared, renewable energy use, industrialization, agriculture productivity, international tourism, urbanization, and forest area. The results indicate a statistically significant negative relationship between GDP squared and CO2 emissions, supporting the Environmental Kuznets Curve (EKC) hypothesis. This suggests that, after an initial increase, CO2 emissions decline as economies transition to service-based and sustainable models. Additionally, the study finds a significant negative correlation between renewable energy use and CO2 emissions, emphasizing the importance of transitioning to cleaner energy sources. Industrialization shows a positive but insignificant relationship with CO2 emissions, indicating a complex interplay between industrial growth, structural changes, and regulatory measures. Agriculture productivity demonstrates a significant negative correlation with CO2 emissions, highlighting the potential of efficient farming methods to reduce environmental impact. International tourism exhibits a significant positive relationship with CO2 emissions, emphasizing the environmental challenges associated with the tourism industry. Urbanization is positively correlated with CO2 emissions, reflecting the energy-intensive nature of urban lifestyles and infrastructure. Surprisingly, forest area shows a significant negative correlation with CO2 emissions, emphasizing the crucial role of

forests as carbon sinks. Overall, these findings underscore the need for sustainable practices and policy interventions to address the intricate dynamics between economic development, energy use, and environmental impact. The study contributes to the existing literature by providing empirical evidence on these relationships (Al-Mulali et al., 2022; Bekun, 2022; Chien et al., 2022; Raza et al., 2021; Tang et al., 2021; Tang et al., 2022; Usman et al., 2022; Voumik & Sultana, 2022; Wang et al., 2021; Wong & Lai, 2022).

Table 6
Outcomes of the DOLS Analysis

Variable	Coefficient	Std. Error	t-Statistic	Prob.
RNE	-0.01089	0.003083	-3.53268	0.0006
IND	0.006184	0.006007	1.02948	0.3059
AP	-0.01596	0.006729	-2.37208	0.0197
GDP	-0.17513	0.173306	-1.01051	0.3149
TR	0.426244	0.102921	4.141464	0.0001
URB	1.012497	0.18113	5.589891	0.0000
FA	0.629787	0.062624	10.05658	0.0000
C	1.024359	1.951911	0.524798	0.601
R-squared	0.995317	Mean dependent var		5.146329
Adjusted R-squared	0.993705	S.D. dependent var		0.716354
S.E. of regression	0.056834	Sum squared resid		0.300402
Long-run variance	0.0084			

The study finds a statistically significant positive correlation between gross domestic product (GDP) and CO2 emissions, with a probability value of 0.3149. This implies that higher GDP levels are associated with increased CO2 output, aligning with prior research (Acheampong & Opoku, 2023; Wang & Zhang, 2021). The observed connection reflects historical patterns of increased industrial activity, electricity use, transportation, and consumerism accompanying economic expansion. However, advancements in energy efficiency, renewable energy, and environmental policies may weaken this relationship over time. The nuanced interplay of economic, technological, and regulatory factors contributes to the complex association between GDP growth and CO2 emissions. The study emphasizes the need for sustainable initiatives and regulations to foster economic growth while mitigating environmental impact.

4.1 Diagnostic Tests

The table 7 shows that all diagnostic test is employed allowed in the model. As a result, none of these tests reject the null hypothesis, it can be claimed that our estimation result is reliable as the problem with residual and autocorrelation are not present in the model, an abnormality which means that the alternative hypothesis is not accepted.

Table 7
Diagnostic Tests

Breusch-Godfrey Serial Correlation LM Test			
F-statistic	0.381	Prob (2,106)	0.684
Obs*R squared	0.900	Prob. chi square (2)	0.638
Normality test			
Jarque Bera	22.176	Prob	0.000

4.2 Stability Test

CUSUM and CUSUM square graphs have been used to assess the stability of the calculated model as shown in the figure. That test statistic is between the critical bound and concludes that the coefficient has not changed throughout the investigation in the model.

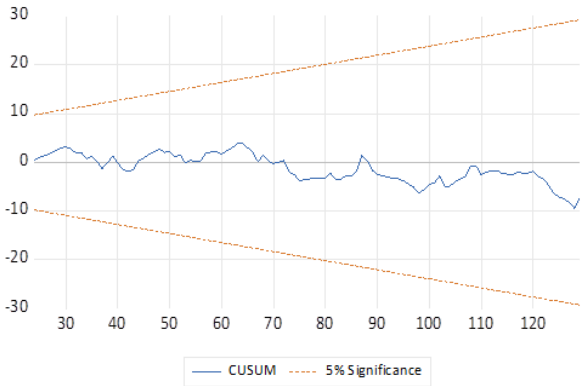

Figure 1: CUSUM Graph

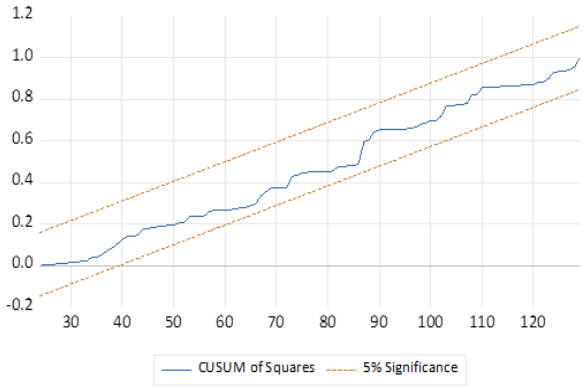

Figure 2: CUSUM of Squares Graph

5. Conclusion

A number of significant new insights regarding the factors that contribute to CO2 emissions are provided by the findings. An indication of the existence of an environmental Kuznets curve is presented through a substantial negative coefficient on GDP squared. This curve implies that after an initial increase, emissions begin to decline at higher income levels. The potential of renewable energy sources to mitigate emissions has been demonstrated, thereby bolstering the conviction that this strategy for achieving sustainable development is sound. Meanwhile, the substantial and positive connections between tourism and urbanization illuminate the climate challenges presented by these socioeconomic factors. Conversely, the lack of statistical significance in the coefficients about industrialization and GDP implies that the relationship between these two variables is more intricate, contingent upon technological and structural factors that constrain emissions. Studies have shown that once implemented on a large scale, reforestation and sustainable agriculture can aid in the reduction of greenhouse gas emissions. When considered collectively, the data furnishes evidence of the intricate and interconnected mechanisms that govern the formation of emission paths. They emphasize the necessity of implementing integrated policies that can restrict the growth of emissions resulting from increasing energy consumption, tourism, urbanization, and industry, while simultaneously promoting clean agriculture, renewable energy, reforestation, and high-quality development that is tailored to the specific circumstances of each nation's progress. These exhaustive and data-driven insights possess the capacity to guide the creation of prosperous models that are inclusive, environmentally friendly, and have minimal carbon footprints.

5.1 Policy Recommendations

First, the policy maker should promote sustained economic growth by prioritizing the character of GDP over its absolute quantity. This consists of promoting the expansion of businesses with reduced carbon emissions, facilitating enhanced energy efficiency, and allocating resources towards renewable and environmentally friendly energy alternatives. Implementing measures that decouple the growth of the economy from the generation of emissions could prove beneficial. Second, encourage the adoption of renewable energy sources through the implementation of regulatory mandates, financial subsidies, and incentives. To augment the share of renewable energy sources in the aggregate energy composition, it is advisable to promote investments in renewable energy infrastructure and research. Establish precise objectives and schedules to guide the integration of renewable energy sources. Third, promote ecologically sustainable agricultural methodologies that mitigate emissions, including but not limited to organic farming, precision farming, and the utilization of natural fertilizers as opposed to synthetic alternatives. Promote the practice of replanting trees after initial sowing in regions with high agricultural productivity. Enact policies that provide monetary incentives to carbon-neutral or carbon-sequestering agricultural systems. Forth, adopt an urban planning strategy that prioritizes the development of green spaces, public transportation, and energy-efficient buildings. The advancement of condensed, pedestrian-friendly urban areas would be advantageous for the

collective welfare of society. Advocate for the formulation of policies that promote the conservation of verdant spaces and environmentally responsible land use in urban environments. These public policy recommendations underscore the importance of a comprehensive approach that considers the unique characteristics of each country (Pakistan, India, and Bangladesh) and the specific challenges they encounter. An effective approach to addressing the issue of CO2 emissions while simultaneously ensuring economic growth and development could be through the exchange of best practices and collaboration between these nations on regional environmental initiatives.

Authors Contribution

Samar Abbas: Initiated the core idea of performed data analysis and drafting.
Rehana Kousar: Study design, Concept topic idea, conclusion, supervised overall study
Muhammad Sharyar: Provided guidance for data analysis, reviewed, supervision direction
Rana Sharjeel Akhtar: Reviewed and revised overall quality and writeup of the manuscript

Conflict of Interests/Disclosures

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