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Drivers of Carbon Emissions in South Asia: Analyzing Economic Growth, Urbanization, Tourism, Industrialization, and Renewable Energy

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Abstract

Rising CO_2 emissions pose a global challenge, including in South Asia. This study examines the determinants of CO_2 emissions—economic growth, urbanization, tourism, industrialization, renewable energy, agriculture, and forest area—using panel data (1990–2021) from South Asian countries. Dynamic Ordinary Least Squares (DOLS) and panel unit root tests reveal long-run relationships. Urbanization, tourism, and agricultural value-added significantly increase CO_2 emissions, while economic growth, renewable energy, and forest area negatively correlate with emissions. The findings suggest that energy-intensive urbanization, tourism, and agricultural expansion drive emissions, whereas renewable energy adoption and forest conservation mitigate them. Policymakers must prioritize sustainable urbanization, green tourism, and renewable energy transitions to curb emissions while fostering economic development.

Keywords: CO_2 Emissions, Economic Growth, Urbanization, Tourism, Renewable Energy Use, Agriculture Sector, South Asia

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1. Introduction

Environmental degradation has become a major concern for countries seeking to balance economic development with ecological sustainability. Population growth, expanding consumption, and industrial activity have increased the pressure placed on natural resources. Baloch et al. (2023) emphasize the importance of environmental awareness and understanding in addressing environmental damage. Carbon dioxide (CO_2) emissions are particularly important because they contribute to climate change and are closely associated with the combustion of fossil fuels and biomass. Moreover, rising energy demand, economic activity, and agricultural production can increase emissions through different channels (Asumadu-Sarkodie & Owusu, 2016). Consequently, identifying the factors associated with CO_2 emissions is necessary for developing policies that support economic activity while limiting environmental deterioration. These relationships are especially relevant to South Asian economies, where development priorities often coincide with increasing demands for energy, infrastructure, and natural resources.

Economic growth and CO_2 emissions are linked through production, consumption, and the energy required to support economic activity. Growth in the output of goods and services can increase electricity demand, transport activity, and industrial fuel consumption. However, the environmental consequences of growth depend partly on the energy mix, production technologies, and resource-use efficiency. In developing countries, reliance on fossil fuels may intensify the emissions associated with expanding economic activity. Therefore, economic development and environmental protection should be examined together rather than treated as competing objectives. Industrialization is particularly relevant because establishing and expanding production facilities can increase energy demand and pollution. Nevertheless, differences in industrial structure and technology mean that the size and direction of these relationships require empirical examination rather than assumption. Earlier research has explored links between energy use and economic development, although the implications vary across national settings (Wolde-Rufael & Menyah, 2010).

Urbanization involves an increasing concentration of populations and economic activities in urban areas. It can support employment, infrastructure development, and the efficient delivery of public services. However, rapid urban growth may also increase demand for transport, housing, electricity, and construction materials, thereby placing additional pressure on the environment. Expansion into agricultural land is another concern, particularly where urban development proceeds without coordinated land-use planning (Jiang et al., 2013; Shalaby, 2012). Similarly, concentrating industrial and commercial activities can contribute to local pollution and higher energy consumption. The environmental consequences of urbanization are not uniform: compact development, public transport, and efficient buildings may reduce emissions, while unplanned expansion may increase them (Sadorsky, 2014; Zhang et al., 2017). Examining the relationship in South Asia is therefore important because urban change intersects with the region's infrastructure and energy needs.

Tourism contributes to economic activity through visitor spending, employment, transportation, accommodation, and investment in related services. International travel has expanded considerably over time, creating opportunities for countries to diversify economic activity (Mikayilov et al., 2019). However, tourism development may also increase transport-related fuel consumption, electricity demand, waste generation, and pressure on land and water resources. The construction and operation of hotels, roads, and visitor facilities can further increase environmental burdens, particularly in locations with insufficient infrastructure or weak environmental management. In addition, concentrations of visitors in environmentally sensitive areas may intensify pollution, resource depletion, and ecosystem degradation (Andlib & Salcedo-Castro, 2021). These potential costs do not negate tourism's economic benefits; rather, they highlight the importance of identifying the environmental conditions under which tourism expands. The present study therefore treats international tourism as a distinct explanatory factor when examining CO_2 emissions in the selected South Asian countries.

Renewable energy is generated from naturally replenished sources, including solar, wind, and hydropower. Energy availability is important for production and economic development, although the environmental consequences depend on the technologies and fuels used (Gabr & Mohamed, 2020; Xiong et al., 2014). Greater use of renewable energy may reduce dependence on carbon-

intensive energy sources and support efforts to limit emissions. In addition, investment in renewable technologies can encourage innovation, diversify electricity supply, and create employment opportunities (Belaïd & Zrelli, 2019). Earlier research also identifies environmental and economic benefits associated with renewable energy systems (Akella et al., 2009). However, renewable energy transitions occur alongside continued energy demand from urbanization, agriculture, and industry. Therefore, its association with CO_2 emissions should be evaluated together with other development-related factors. By considering renewable energy alongside economic, demographic, and land-use indicators, this study seeks to provide a broader assessment of emissions in South Asia.

1.1. Objectives of the Study

The study aims to address the following primary objectives:

- To explore the impact of economic growth on CO_2 emissions in South Asia.
- To assess the relationship between urbanization and CO_2 emissions across South Asian countries.
- To analyze the environmental impact of tourism on CO_2 emissions in South Asian countries.
- To examine how industrial development contributes to CO_2 emissions in South Asian countries.
- To analyze the impact of renewable energy consumption on CO_2 emissions in the South Asian region.

The study aims to provide evidence to help policymakers in the selected South Asian economies understand how economic growth, urbanization, tourism, industrialization, and renewable energy use are associated with CO_2 emissions. In addition, the empirical model includes agriculture and forest area to account for relevant land-use and production-related influences. The findings may inform policies that encourage cleaner energy, better urban planning, and more sustainable economic activities. However, policy recommendations must reflect the direction and statistical significance of the estimated relationships rather than assume that every explanatory variable has a measurable effect. The analysis is intended to support discussion of development pathways that can accommodate economic needs while reducing environmental pressure, particularly in countries experiencing continued urban expansion.

2. Literature Review

The literature review considers evidence on the economic, demographic, energy-related, and land-use factors associated with CO_2 emissions. Studies differ in their geographic coverage, estimation techniques, and reported relationships; therefore, direct comparison requires attention to these differences. The following sections review the findings for economic growth and urbanization, tourism and industrialization, renewable energy, and agriculture and forest area. In addition, the review identifies how the present analysis relates to earlier work on South Asia, where several of the same explanatory factors have already been examined (Abbas et al., 2023; Usman et al., 2022).

2.1. Economic Growth and Urbanization in Relation to Carbon Emissions

Alnour (2021) investigated the association between economic growth and environmental pollution in Turkey using data covering 1970–2017 and an autoregressive distributed lag (ARDL) approach. The study reported a positive short-run relationship between economic growth and environmental degradation, whereas the long-run effect was positive but statistically insignificant. In addition, the findings did not support the Environmental Kuznets Curve (EKC) hypothesis. These results illustrate why the relationship between economic activity and environmental deterioration should not be assumed to remain constant across periods or economies. They also provide a useful point of comparison for interpreting an insignificant estimated growth coefficient in the present South Asian panel.

Balsalobre-Lorente et al. (2020) examined tourism, globalization, energy consumption, economic growth, and environmental degradation in developed economies over 1994–2014. Their analysis associated energy consumption, tourism, and economic expansion with environmental pressures, while indicating that the relationship involving tourism could change as globalization progressed.

Similarly, their findings suggested that the composition and efficiency of energy use are important when evaluating environmental outcomes. However, evidence drawn from developed economies cannot be transferred automatically to South Asia, where energy infrastructure and production structures may differ. The present study therefore assesses the relevant factors using observations from four South Asian countries rather than relying solely on evidence from other regions.

Similarly, Shaheen et al. (2020) examined the relationships among income, energy consumption, urbanization, and CO_2 emissions in Pakistan using data from 1972 to 2014. Their results indicated that energy consumption and GDP were associated with higher emissions, whereas the estimated relationships for industrialization and urbanization were not statistically significant. The authors emphasized the relevance of energy infrastructure, technological improvement, and differences between urban and rural areas for emissions policy. These findings demonstrate that the environmental implications of urbanization may depend on country-specific economic conditions. Therefore, evidence from Pakistan provides a useful comparison, but it does not establish whether the same relationships hold across the wider South Asian panel.

Majeed and Tauqir (2020) evaluated the relationships among industrialization, urbanization, economic growth, energy consumption, and carbon emissions across 156 countries classified by income level over 1990–2014. They reported positive associations of industrialization and urbanization with emissions, while the role of economic growth varied across income groups. The findings indicate that changes in productive activity and settlement patterns can contribute to environmental pressure, but their effects may differ with the stage of economic development. In addition, the authors highlighted the relevance of cleaner energy and financial support for more sustainable industrial and urban activity. These differences underscore the need for an empirical specification appropriate to the economies under examination rather than a universal assumption about the environmental consequences of development.

2.2. Tourism and Industrialization in Relation to Carbon Emissions

Chau et al. (2023) examined tourism, economic development, and eco-innovation in relation to environmental degradation in China, using data for 1988–2020 and a nonlinear ARDL (NARDL) approach. Their analysis associated several tourism and economic indicators with greater environmental pressure, while eco-innovation was linked to improved environmental outcomes. The findings suggest that the environmental consequences of tourism need to be considered alongside technological progress and economic conditions. However, the present study focuses on a panel of South Asian economies and uses international tourist arrivals as its tourism indicator. Consequently, its estimates should be interpreted as evidence relating to that measure rather than to every dimension of tourism-related economic activity.

Opoku and Aluko (2021) investigated the environmental implications of industrialization in 37 African countries using panel quantile regression for 2000–2016. Their analysis indicated that industrialization can contribute to environmental deterioration, although the estimated relationship may vary across the distribution of environmental outcomes. The study highlights the relevance of production technologies and environmental regulation when industrial activity expands. For South Asia, this evidence suggests a possible emissions-related channel through industrial development; however, whether that channel is statistically apparent in the present model remains an empirical question. Therefore, industrialization is retained as an explanatory variable without presuming a significant effect.

Appiah et al. (2021) analyzed links among energy consumption, industrialization, and CO_2 emissions in sub-Saharan African countries. They reported associations between fossil-fuel use, industrial activity, urbanization, and environmental degradation, and their analysis also considered directions of causality. These results are relevant because expansion of industrial production can increase dependence on carbon-intensive energy. Nevertheless, the energy structure and industrial composition of South Asian economies may differ from those of the countries included in that study. Comparing the findings helps assess whether the expected industrialization–emissions relationship is supported within the selected South Asian sample.

2.3. Renewable Energy Use and Carbon Emissions

Research on renewable energy provides a basis for expecting a negative association between cleaner energy use and CO_2 emissions. For example, Adebayo (2022) examined renewable energy consumption and environmental sustainability in Canada, finding evidence of an inverse relationship between renewable energy use and environmental degradation. Similarly, Bilgili et al. (2016) investigated the dynamic role of renewable energy consumption in relation to CO_2 emissions. These studies provide a relevant foundation for assessing renewable energy in the South Asian panel. However, the direction and magnitude of the relationship must still be established from the study's own estimates, particularly because the energy mix and degree of renewable energy adoption vary across economies.

Adebayo (2022) used a dynamic ARDL framework to study renewable energy consumption and environmental sustainability in Canada for 1990–2018. The findings indicated that renewable energy use, globalization, and political risk were inversely associated with environmental degradation in the estimated specification. In addition, frequency-domain analysis was used to investigate predictive relationships involving emissions and several economic indicators. Although this research was conducted outside South Asia, it offers an empirical comparison for the proposed negative relationship between renewable energy consumption and carbon emissions. Its results should, however, be interpreted within the Canadian context rather than assumed to apply unchanged to the four countries examined here.

2.4. Agriculture, Forest Area, and Carbon Emissions

Göksu and Göçoğlu (2023) assessed the relationships among urbanization, forestation, internet use, energy consumption, GDP per capita, and environmental degradation in Türkiye using data for 1990–2020. Their ARDL analysis indicated long-run relationships among the included variables and examined possible directions of causality. The findings are relevant to the present study because forest coverage and energy-related development may influence environmental outcomes through different mechanisms. However, the use of different environmental indicators and estimation settings makes direct numerical comparison inappropriate. The literature instead provides a basis for considering forest area as an additional factor alongside conventional economic and demographic measures.

Khurshid et al. (2022) investigated the association between agricultural value added and CO_2 emissions in Pakistan, considering globalization and energy consumption over 1971–2021. Their nonlinear ARDL approach identified asymmetric effects, indicating that positive and negative changes in agricultural activity were not associated with identical emissions responses. The findings suggest that agricultural production and its energy requirements deserve attention when assessing environmental pressures in developing economies. Similarly, they underline the importance of distinguishing agricultural output from the technologies and inputs used to produce it. The present study includes agricultural value added as an explanatory variable but does not estimate asymmetric responses; its conclusions are therefore limited to the reported panel association.

Usman et al. (2022) examined agriculture value addition, energy utilization, tourism, and environmental degradation in South Asia using data for 1995–2017. They found that several measures of productive activity and nonrenewable energy use were associated with environmental deterioration, whereas renewable energy use was linked to improved environmental conditions. This study provides a particularly important point of comparison because it addresses the same geographic region and several overlapping variables. The present research extends the period to 1990–2021, includes urbanization, industrialization, and forest area within the reported specification, and estimates long-run relationships using DOLS. Nevertheless, the contribution should be described as a difference in coverage and model specification, rather than as the first examination of these relationships in South Asia.

The reviewed literature indicates that emissions may be associated with economic growth, urbanization, tourism, industrialization, agricultural activity, renewable energy use, and forest resources. However, the direction and significance of these relationships vary by country characteristics, how environmental outcomes are measured, and econometric specification (Appiah et al., 2021; Majeed & Tauqir, 2020; Shaheen et al., 2020). Studies also suggest that energy

composition can influence whether economic and demographic changes translate into greater environmental pressure (Adebayo, 2022; Bilgili et al., 2016). Consequently, an integrated assessment helps examine these factors within a common regional framework. Such an assessment must also recognize the limits of pooled coefficients, which may conceal differences among the countries included in the sample.

South Asian countries face the combined demands of economic development, urban growth, transport activity, agricultural production, and energy provision. Previous research has already examined important subsets of these relationships in the region (Abbas et al., 2023; Usman et al., 2022). However, this study brings economic growth, urbanization, tourism, industrialization, renewable energy use, agricultural value added, and forest area together in a single panel specification for Pakistan, Bangladesh, India, and Sri Lanka over 1990–2021. This common framework allows comparison of the relative directions and statistical significance of the included long-run associations. In addition, the findings may clarify which factors exhibit statistically supported links with emissions in the estimated model. The claimed contribution is therefore the combined variable coverage, observation period, and empirical comparison, not an assertion that the relevant relationships have never previously been studied.

2.5. Conceptual Framework

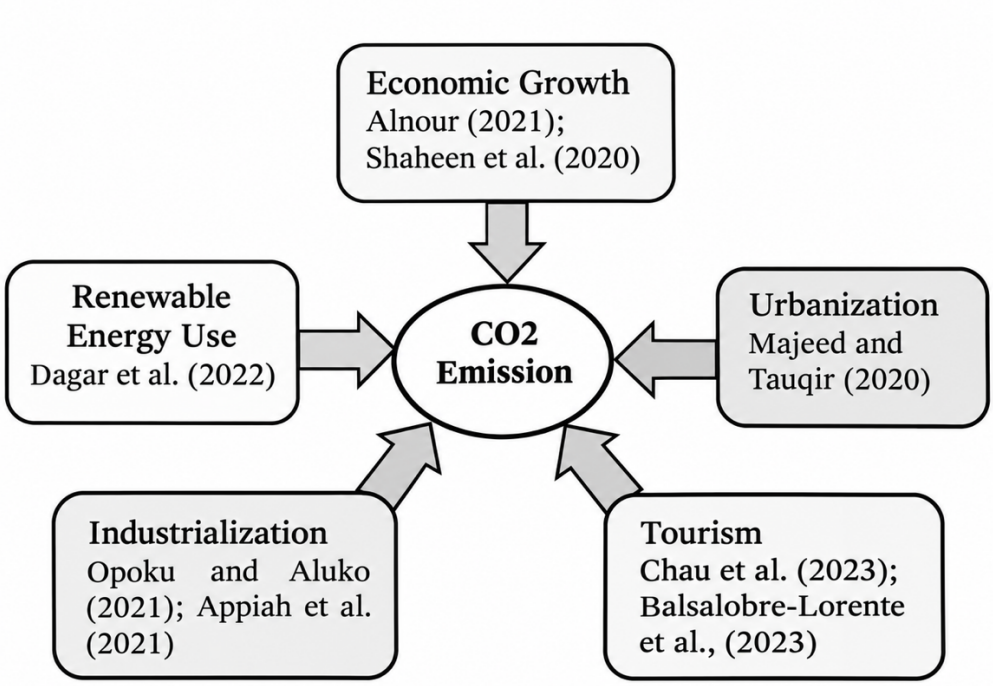


Figure 1: Conceptual Framework

The conceptual framework brings together the economic, demographic, energy-related, and land-use factors considered in the study. Economic growth, urbanization, tourism, and industrialization may increase energy demand and resource use, although the environmental consequences depend on the structure of these activities (Balsalobre-Lorente et al., 2020; Majeed & Tauqir, 2020; Shaheen et al., 2020). Renewable energy use may reduce reliance on carbon-intensive energy sources (Bilgili et al., 2016). In addition, agricultural production can create emissions-related pressures, while forest resources are relevant to carbon storage and environmental quality (Khurshid et al., 2022; Waheed et al., 2018). The figure illustrates several primary explanatory relationships; however, agriculture and forest area are also included in the empirical model, even though they are not shown in the illustration. Therefore, interpret the framework using the full set of variables identified in the model specification.

3. Models and Methodology

3.1. Model Specification

To examine the long-run association of economic growth, urbanization, international tourism, industrialization, renewable energy consumption, agricultural value added, and forest area with CO_2 emissions in the selected South Asian countries, the following functional relationship is specified. The model estimates the relationship between emissions and each included explanatory variable while accounting for the other variables in the specification.

CO_2 emissions = f (economic growth, urbanization, tourism, industrialization, renewable energy use, agricultural productivity, forest area)

$$CO_{2it} = \beta_o + \beta_1 EG_{it} + \beta_2 URB_{it} + \beta_3 TR_{it} + \beta_4 IND_{it} + \beta_5 RNE_{it} + \beta_6 AVA_{it} + \beta_7 FA_{it} + u_{it}$$

$\boldsymbol{\beta_1}$ ***to*** $\boldsymbol{\beta_8}$ CO_2 emissions are the dependent variable, while economic growth (EG), urbanization (URB), tourism (TR), industrialization (IND), renewable energy consumption (RNE), agricultural value added (AVA), and forest area (FA) are explanatory variables. The model includes an intercept and an error term; the subscripts i and t denote the cross-sectional unit and time period, respectively. The estimated coefficients represent conditional associations within the specified panel model. Interpret them in light of the measurement scales and any transformations applied to the variables, as these determine whether coefficients represent unit changes or elasticities.

3.2. Data and Source

The analysis uses annual panel data for 1990–2021 obtained from the World Development Indicators (WDI). The four countries included are Pakistan, Bangladesh, India, and Sri Lanka. The dependent variable is CO_2 emissions, while the explanatory variables are economic growth (EG), urbanization (URB), international tourism (TR), industrialization (IND), renewable energy consumption (RNE), agricultural value added (AVA), and forest area (FA). Table 1 identifies the measures and expected directions of association. However, the reported descriptive statistics suggest that some variables may have been transformed before estimation; the appropriate scale must therefore be read in conjunction with the underlying data and model output. This study does not report additional country-level models or alternative estimation periods.

Table 1: Description of Variables

Code	Variables Name & Measurement Unit	Source	Expected Sign	Reasoning
Dependent Variables				
CO_2	CO_2 emission (Metric tons)	WDI		
Independent Variables				
EG	Economic Growth (Gross Domestic Product (Constant $)	WDI	(-/+)	Economic growth may lead to more CO_2 emissions as production and consumption rise (+). However, in economies transitioning to cleaner technologies, emissions may decline (-)
URB	Urbanization (Proportion of urban population relative to total population)	WDI	(+/-)	Urbanization could increase emissions through greater industrial and energy use (+). Conversely, sustainable urban planning may lower emissions (-)
TR	Tourism (Number of arrivals)	WDI	(+)	Tourism, particularly international, is associated with increased travel and energy use, leading to higher emissions.
IND	Industrialization (Industrial value-added growth rate)	WDI	(+)	Industrialization often involves energy-heavy processes, which can result in higher CO_2 emissions.
RNE	Renewable energy consumption as a percent of total energy consumption	WDI	(-)	A higher share of sustainable energy in the energy mix can reduce dependence on fossil fuels, lowering emissions.
Control Variables				
AVA	Agriculture value-added as a percent of GDP	WDI	(-/+)	Economies with a greater focus on agriculture may see lower emissions, as this sector generally requires less energy compared to industry (-). If the agricultural sector relies heavily on mechanization and fossil fuel-based technologies, the sign could potentially be positive (+).

FA	Forest area (square KM)	WDI	(-)	Forests act as carbon sinks, absorbing CO_2 and offsetting emissions, so an increase in forest area typically reduces net emissions.

Source: By the author

3.2.1. Definition of Variables

CO_2 Emissions

Carbon dioxide is an important greenhouse gas associated with anthropogenic climate change. Human activities, particularly the combustion of carbon-based fuels, release CO_2 into the atmosphere and contribute to changes in the Earth's energy balance. These changes have implications for temperature, climatic conditions, sea levels, and agricultural production. In addition, environmental deterioration can affect the sustainability of economic development, making emissions a relevant indicator in studies of growth and energy use (Shahbaz et al., 2012). The dependent variable in this study is the WDI measure of CO_2 emissions, as identified in Table 1. Its precise statistical interpretation depends on the unit and any transformation used in estimation.

Economic Growth

Economic growth describes changes in economic output over time. The Environmental Kuznets Curve (EKC) hypothesis proposes that environmental pressure may initially rise with economic development and subsequently decline after income reaches a turning point (Heidari et al., 2015). However, the present study reports a linear growth term and does not estimate a squared income variable. Consequently, its results cannot be interpreted as a formal test of the EKC hypothesis. Economic growth may affect emissions through production, household demand, industrial activity, and technological change; therefore, the direction of the relationship remains an empirical question in the specified model.

Urbanization

Urbanization refers to the concentration of people and economic activities in urban settlements. Expanding cities can increase energy demand through transport, commercial activity, housing, and construction, potentially raising CO_2 emissions (Sadorsky, 2014). In addition, urban expansion may alter agricultural land use and the distribution of infrastructure (Jiang et al., 2013). However, urbanization can also facilitate more efficient public transport, compact development, and improved building performance. Zhang et al. (2017) therefore provide a relevant basis for considering both positive and negative environmental effects. The present study measures urbanization using the share of the population living in urban areas, as stated in Table 1, rather than a direct measure of urban transport or infrastructure intensity.

International Tourism

International tourism involves travel and associated services such as transport, accommodation, recreation, and visitor infrastructure. These activities can support employment and income generation; however, they may also increase energy use, waste, and pressure on land and natural resources. Tourism infrastructure development can contribute to environmental degradation when it is not accompanied by suitable planning and management (Azam et al., 2018; Baloch et al., 2023). Similarly, increased transport activity may raise emissions, although the relationship depends on travel patterns and energy sources. The tourism variable used here is international tourist arrivals. Accordingly, its estimated association with CO_2 emissions should not be treated as a direct measurement of all emissions generated by the tourism sector.

Industrialization

Industrialization includes the establishment of new production facilities and the expansion of existing industrial activities. It can support employment, output growth, and economic diversification, but it may also increase energy consumption and demand for carbon-intensive inputs. Wang et al. (2020) examined related links among industrialization, urbanization, and CO_2 emissions. Similarly, Patnaik (2018) discussed environmental pressures associated with industrial development and the need for sustainable responses. Nevertheless, emissions outcomes may differ according to production technologies, energy efficiency, and regulatory conditions. The present

study uses an industrial value-added growth indicator, which should be distinguished from the physical volume of industrial production or the industrial share of GDP.

Renewable Energy Use

Renewable energy contributes to energy diversification and may reduce reliance on fossil fuels. Technologies such as solar, wind, and hydroelectric power can support energy supply while limiting some sources of carbon emissions, although their environmental implications vary by technology and implementation context (Akella et al., 2009; Chel & Kaushik, 2018). In addition, renewable energy investment can support longer-term development and energy security. However, a higher renewable share does not automatically establish that every component of economic activity is low-carbon. The present study measures renewable energy consumption as a percentage of total final energy consumption, as indicated in Table 1. This distinction is important when interpreting the estimated association between renewable energy use and CO_2 emissions.

Agriculture value-added

Agricultural production requires land, energy, machinery, fertilizer, irrigation, and other inputs. Consequently, the expansion or intensification of agricultural activity may increase energy-related emissions, particularly when production relies on fossil fuels (Gokmenoglu & Taspinar, 2018). In addition, this relationship can vary with farming practices, technology, and the composition of agricultural output. Khurshid et al. (2022) provide evidence of differing emissions responses to changes in agriculture-related activity in Pakistan. The present study uses agricultural value added as a percentage of GDP. Therefore, this indicator captures the sector's contribution to economic output rather than a direct physical measure of agricultural productivity or agricultural greenhouse gas emissions.

Forest Area

Forests contribute to carbon storage by absorbing atmospheric CO_2 and accumulating carbon in vegetation and soils. Changes in forest area may therefore be associated with environmental conditions, although the strength of that association depends on forest characteristics, management, and land-use practices. In addition, protecting forest resources can support ecosystems and reduce pressures linked to land degradation. Waheed et al. (2018) examine relationships involving forests, agriculture, renewable energy, and CO_2 emissions. The present study includes forest area as an explanatory indicator. However, the coefficient for forest area should be interpreted as an estimated statistical association, not a direct measure of the carbon sequestered by each additional unit of forest land.

3.3. Estimation Technique

Figure 2 presents the sequence of activities described in the empirical approach, beginning with variable selection and the review of relevant literature, followed by model specification and preliminary time-series tests. The study then assesses the integration properties of the variables and examines evidence of cointegration before estimating the reported long-run coefficients using dynamic ordinary least squares (DOLS). This sequence is intended to reduce the risk of interpreting unrelated nonstationary series as a meaningful long-run relationship. However, the suitability of the final estimator depends on the integration characteristics of the variables and the assumptions of the panel specification. Accordingly, interpret the diagnostic results carefully alongside the reported estimates. The following econometric approaches are employed on the data to achieve the study's objectives:

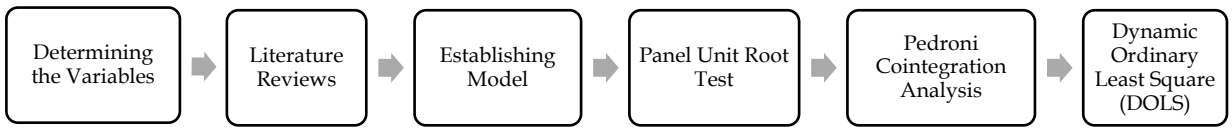


Figure 2: Methodological Approach

3.3.1 Unit Root Test

Unit-root testing assesses whether the variables are stationary in levels or become stationary after differencing. This distinction matters because regression involving nonstationary variables may produce misleading relationships when the series are not cointegrated. The study reports augmented Dickey–Fuller (ADF), ADF-GLS, and Phillips–Perron (PP) test statistics as preliminary diagnostics. The tests are intended to identify the order of integration before evaluating long-run relationships. However, different reported tests do not always lead to identical conclusions for every variable. Therefore, the stated integration order must align with the test statistics and p-values, especially for industrialization, whose level tests in Table 3 are statistically significant.

3.3.2 Pedroni Cointegration Test

The Pedroni procedure evaluates evidence of cointegration in panel data through several statistics that allow different assumptions about the adjustment process across cross-sectional units. The reported null hypothesis is that no cointegrating relationship exists. Rejection of that null by an individual statistic provides evidence against the absence of cointegration, whereas a nonsignificant result does not establish cointegration. Because the Pedroni tests can yield different outcomes, interpretation should consider the pattern of results rather than describe every statistic as supportive. The study also reports the Kao residual-based test as an additional assessment of long-run association.

H_0: There is no long-run Cointegration

H_1: There is a long-run cointegration

3.3.3 Dynamic Ordinary Least Squares (DOLS)

Dynamic Ordinary Least Squares (DOLS) is used to estimate long-run coefficients when the specified variables meet the relevant conditions for cointegration analysis. The approach augments the long-run regression with leads and lags of changes in the explanatory variables to address potential endogeneity and serial-correlation concerns. However, DOLS does not automatically eliminate all omitted-variable bias or resolve every model specification problem. Its reliability depends on the integration properties of the data, the cointegration relationship, and the estimation choices. Reported p-values are assessed against conventional statistical significance thresholds; when a p-value exceeds the selected threshold, the null of a zero coefficient is not rejected. Therefore, statistically insignificant coefficients should not be described as established increases or reductions in emissions. The current paper reports long-run DOLS estimates, rather than demonstrating causal effects or short-run dynamic responses.

4. Empirical Findings and Discussion

The empirical analysis begins with the descriptive statistics of the variables used in the model. These statistics provide information on central tendency, dispersion, and distributional shape, which helps interpret the range of observations included in the panel.

Table 2: Descriptive Statistics of the Variables

Variables	Mean	Max.	Min.	S.D.	Skew.	Kurt.
CO_2	5.154	6.390	4.035	0.712	0.165	1.946
EG	13.295	14.168	12.549	0.403	0.294	2.553
URB	1.750	1.960	1.542	0.135	-0.221	1.850
TR	5.887	7.253	5.017	0.605	0.618	2.419
IND	6.131	17.374	-5.745	3.464	-0.676	4.920
RNE	50.345	73.160	24.750	12.247	-0.046	2.465
AVA	22.869	34.699	11.633	5.571	0.091	2.366
FA	4.872	5.858	3.161	0.703	0.471	1.669

Source: by the author. ***Abbreviations:*** ***CO_2****, CO_2 Emissions;* ***EG****, Economic Growth;* ***URB****, Urbanization;* ***TR****, International Tourism;* ***IND****, Industrialization;* ***RNE****, Renewable energy use;* ***AVA****, Agriculture productivity;* ***FA****, Forest Area*

Table 2 reports descriptive statistics for the dependent variable and explanatory indicators across the study sample. The mean CO_2 measure is 5.154, with a minimum of 4.035, a maximum of 6.390, and a standard deviation of 0.712. Its skewness of 0.165 suggests a relatively modest positive skew, while its kurtosis is 1.946. Renewable energy consumption has a mean of 50.345 and ranges from 24.750 to 73.160, with a standard deviation of 12.247, indicating appreciable variation across the

observations. Similarly, industrialization has a mean of 6.131, a minimum of −5.745, a maximum of 17.374, and a standard deviation of 3.464. Its negative minimum is consistent with possible contractions in the industrial value-added growth indicator and should not automatically be treated as a data error. The industrialization distribution has skewness of −0.676 and kurtosis of 4.920, suggesting a more pronounced concentration and tail pattern than some other indicators. Urbanization has a mean of 1.750, varies between 1.542 and 1.960, and has a standard deviation of 0.135. The reported urbanization statistic therefore changes over a comparatively narrow range. International tourism has a mean of 5.887, a minimum of 5.017, and a maximum of 7.253, with skewness of 0.618 and kurtosis of 2.419. Forest area has a mean of 4.872, ranges between 3.161 and 5.858, and has a standard deviation of 0.703. In addition, agricultural value added has a mean of 22.869 and ranges from 11.633 to 34.699; its standard deviation of 5.571 indicates substantial variation in the recorded indicator. The corresponding skewness value of 0.091 is close to zero, and the kurtosis is 2.366. Economic growth, represented by the reported GDP indicator, has a mean of 13.295, a minimum of 12.549, a maximum of 14.168, and a standard deviation of 0.403. However, the numerical scales of some reported indicators do not directly match the untransformed measurement descriptions in Table 1. Therefore, interpret the descriptive statistics cautiously until the transformation choices underlying Table 2 are confirmed. These descriptive differences do not independently establish the statistical significance or causal direction of any relationship in the subsequent regression results.

The descriptive statistics indicate differences in the variability and distribution of the included indicators. Renewable energy consumption and industrialization exhibit relatively substantial dispersion, whereas the reported urbanization and economic-growth measures vary over narrower ranges. However, skewness and kurtosis alone do not establish whether a panel regression satisfies its econometric assumptions. In addition, the meaning of the summary values depends on whether the underlying variables were entered in levels, percentages, or logarithmic form. Consequently, the descriptive results should be read as a preliminary characterization of the sample rather than evidence of the size or significance of the estimated long-run relationships.

Table 3: Panel Unit-Root Analysis

Variables	ADF Test		ADF-GLS Test		PP Test		Result
	Level	1st diff	Level	1st diff	Level	1st Diff	
CO_2	-1.55 (0.504)	-11.067 (0.000) *	-1.146 (0.250)	-11.104 (0.000) *	-1.599 (0.4797)	-11.067 (0.000) *	I (1)
EG	-2.163 (0.2211)	-11.11 (0.000) *	-2.092 (0.038) **	-11.043 (0.000)	-2.257 (0.188)	-11.11 (0.000) *	I (1)
URB	-1.585 (0.488)	-10.781 (0.000) *	-1.529 (0.129)	-10.824 (0.000) *	-1.737 (0.410)	-10.7956 (0.000) *	I (1)
TR	-1.671 (0.444)	-11.018 (0.000) *	-1.316 (0.191)	-11.055 (0.000) *	-1.721 (0.418)	-11.018 (0.000) *	I (1)
IND	-8.591 (0.000) *	-14.643 (0.000) *	-8.572 (0.000) *	-3.555 (0.000) *	-8.78 (0.000) *	-41.26 (0.000) *	I (1)
RNE	-1.116 (0.71)	-10.53 (0.000)	-0.776 (0.404)	-10.55 (0.000)	-1.473 (0.544)	-10.56 (0.000)	I (1)
AVA	-1.687 (0.440)	-11.125 (0.000) *	0.0212 (0.980)	-9.714 (0.000) *	-1.933 (0.316)	-11.176 (0.012) **	I (1)
FA	-1.511 (0.525)	-16.106 (0.000) *	-0.558 (0.0001) *	-16.135 (0.000) *	-2.004 (0.285)	-16.315 (0.000) *	I (1)

Source: by the author. ***Note:*** **** denotes the 1% significance level, ** the 5% significance level, and * the 10% significance level. The values in parentheses represent p-values, whilst the values above them denote test statistic values.*

Table 3 reports the unit-root test results for the variables used in the analysis. Several indicators are nonstationary in levels and stationary after first differencing, which is consistent with integration of order one. However, the level statistics for industrialization are reported as statistically significant, while the result column classifies that variable as I(1). A similar discrepancy appears for at least one reported test of forest area. Therefore, the conclusion that all variables are I(1) is not fully supported by the table as presented. The order of integration should be checked against the original test output

before the cointegration and DOLS specification is regarded as fully validated. These reporting issues do not alter the numerical values reproduced in Table 3.

Table 4: Pedroni Cointegration Analysis

Within Dimensions Cointegration Test	**Statistic**	**Prob.**
Panel v-Statistic	0.015	0.7426
Panel rho-Statistic	0.321	0.2491
Panel PP-Statistic	-4.652	0.0000
Panel ADF-Statistic	-5.547	0.0001
Between Dimensions		
Group rho-Statistic	2.019	0.6311
Group PP-Statistic	-3.910	0.0091
Group ADF-Statistic	-2.389	0.0351
Kao Residual Cointegration Test		
ADF	-2.383	0.0001

Source: by the author.

Table 4 presents the Pedroni and Kao cointegration test results. Within the Pedroni within-dimension tests, the panel v-statistic (p = .7426) and panel rho-statistic (p = .2491) do not reject the null of no cointegration. However, the panel PP-statistic (p < .001) and panel ADF-statistic (p = .0001) indicate evidence against that null. The between-dimension results are similarly mixed: the group rho-statistic (p = .6311) is nonsignificant, whereas the group PP-statistic (p = .0091) and group ADF-statistic (p = .0351) support cointegration. In addition, the reported Kao test (p = .0001) provides further evidence against the absence of a long-run relationship. Therefore, the combined results offer support for cointegration from several statistics, but not from every test reported. This qualification is important when describing the empirical basis for the subsequent DOLS estimation.

Table 5: Dynamic Ordinary Least Squares (DOLS) Estimates

Dependent Variable: CO_2 Emissions				
Variables	**Coefficients**	**Standard Error**	**T. Statistics**	**P. Value**
EG	0.1751	0.1733	1.0105	0.3149
URB	1.0124	0.18113	5.5898	0.0000***
TR	0.4262	0.1029	4.1414	0.0001***
IND	0.0061	0.0060	1.0294	0.3059
RNE	-0.0108	0.0030	-3.5326	0.0006***
AVA	0.0159	0.0067	2.3720	0.0197**
FA	-0.6297	0.0626	-10.0565	0.0000***
C	1.0243	1.9519	0.5247	0.601

Source: by the author.

Table 5 reports the estimated long-run DOLS coefficients for CO_2 emissions. Urbanization (β = 1.0124, p < .001), international tourism (β = 0.4262, p = .0001), and agricultural value added (β = 0.0159, p = .0197) are positively and statistically significantly associated with emissions. In contrast, renewable energy consumption (β = −0.0108, p = .0006) and forest area (β = −0.6297, p < .001) have negative and statistically significant coefficients. Economic growth (β = 0.1751, p = .3149) and industrialization (β = 0.0061, p = .3059) have positive but statistically insignificant estimates. These findings identify conditional associations within the specified panel; they should not be interpreted as proof of causal effects. In addition, coefficient magnitudes cannot be compared directly without accounting for differences in variable measurement and transformation.

4.1 Effect of Economic Growth on CO_2 Emissions

The DOLS coefficient for economic growth is positive (β = 0.1751), but the association is not statistically significant (p = .3149). Therefore, the model does not provide sufficient evidence of a nonzero long-run relationship between the reported economic-growth measure and CO_2 emissions after accounting for the other included variables. Earlier research has linked growth and energy use to environmental pressures in South Asia, although the reported effects differ across studies and model specifications (Shaheen et al., 2020; Usman et al., 2022). The insignificant estimate in the present analysis may reflect differences in energy composition, the structure of economic activity, or the available variation in the panel. However, these possible explanations are not separately tested and should not be presented as established mechanisms. The result also does not establish an

EKC relationship, because the model does not include the nonlinear income term required to test that hypothesis.

4.2 Effect of Urbanization on CO_2 Emissions

Urbanization has a positive and statistically significant estimated association with CO_2 emissions ($\beta = 1.0124$, $t = 5.5898$, $p < .001$). This finding is consistent with the possibility that urban expansion is accompanied by greater demand for energy, transport, buildings, and infrastructure. Studies of urbanization and environmental pressure also identify the relevance of settlement patterns and urban energy use (Azam & Khan, 2016; Huo et al., 2020; Sadorsky, 2014). However, the coefficient should not automatically be interpreted as a one-unit physical increase in emissions without first confirming the transformations applied to the variables. In addition, a significant association does not mean that every type of urban development increases emissions to the same extent. More efficient transport, building technologies, and land-use planning may be relevant policy responses, although their individual effects are not estimated in this study.

4.3 Effect of Tourism on CO_2 Emissions

International tourism is positively and significantly associated with CO_2 emissions in the estimated DOLS model ($\beta = 0.4262$, $t = 4.1414$, $p = .0001$). This result is consistent with the environmental pressures that can accompany tourism-related transport, accommodation, and infrastructure development. Previous research has also examined tourism and environmental degradation in different national and regional settings (Andlib & Salcedo-Castro, 2021; Azam et al., 2018; Baloch et al., 2023; Usman et al., 2022). However, the present variable measures tourist arrivals rather than the direct carbon footprint of travel or visitor spending. Therefore, the coefficient indicates an association between the selected tourism indicator and emissions; it does not isolate the contribution of particular tourism businesses or technologies. The findings nonetheless provide a reason to consider transport efficiency, energy use in accommodation, and environmental management when discussing tourism development in South Asia.

4.4 Effect of Industrialization on CO_2 Emissions

The estimated coefficient for industrialization is positive but statistically insignificant ($\beta = 0.0061$, $p = .3059$). Thus, the model does not establish a statistically reliable long-run association between the industrialization indicator and CO_2 emissions in the selected sample. Although earlier studies report environmental pressures associated with industrial activity (Appiah et al., 2021; Opoku & Aluko, 2021; Wang et al., 2020), the findings may depend on the measure of industrialization, energy sources, and country characteristics. Moreover, the present indicator captures industrial value-added growth rather than an aggregate measure of industrial emissions. Consequently, the lack of statistical significance should be reported explicitly and not taken to mean either that industrial development is environmentally harmless or that its effect has been demonstrated to be positive.

4.5 Effect of Renewable Energy on CO_2 Emissions

Renewable energy consumption has a negative and statistically significant coefficient in the DOLS results ($\beta = -0.0108$, $t = -3.5326$, $p = .0006$). This association is consistent with the expectation that a greater contribution from renewable sources can reduce dependence on carbon-intensive energy (Akella et al., 2009; Bilgili et al., 2016). Similar relationships have been examined in earlier studies, including evidence from South Asia and other country settings (Abbas et al., 2023; Adebayo, 2022; Usman et al., 2022). However, the result does not establish that renewable technologies are entirely free of environmental impacts or that the coefficient represents a direct causal reduction in emissions. The reported estimate pertains to renewable energy's share of final energy consumption in the specified model. Therefore, the practical implication is to consider renewable energy deployment alongside energy efficiency and the continuing energy demands of urban and industrial development.

4.6 Effect of Agricultural Value Added on CO_2 Emissions

Agricultural value added has a positive and statistically significant estimated relationship with CO_2 emissions ($\beta = 0.0159$, $t = 2.3720$, $p = .0197$). This finding is consistent with evidence that energy use and production inputs in agriculture can contribute to environmental pressure (Khurshid et al., 2022; Qiao et al., 2019; Usman et al., 2022). Nevertheless, agricultural value added as a share of GDP

is not identical to physical agricultural output or a direct inventory of agricultural greenhouse gases. Accordingly, the results should not be interpreted as showing that a specific quantity of fertilizer use or livestock production causes the estimated change in CO_2 emissions. The association instead indicates that the agricultural indicator is relevant within the selected long-run specification. In addition, the findings support further attention to energy-efficient farming practices and cleaner agricultural production systems, without treating their effects as already measured in this analysis.

4.7 Effect of Forest Area on CO_2 Emissions

Forest area has a negative and statistically significant coefficient in the DOLS estimation ($\beta = -0.6297$, $t = -10.0565$, $p < .001$). This finding is consistent with the environmental relevance of forest resources and carbon storage, as discussed in prior research (Akinbami et al., 2003; Waheed et al., 2018). However, the coefficient estimates a panel association and should not be treated as a direct measure of biological sequestration or the amount of CO_2 absorbed by a particular forest area. The model does not separately identify forest quality, land management, or changes in vegetation. Therefore, the finding supports consideration of forest protection and sustainable land management within emissions policy, while leaving the specific mechanisms and magnitudes for further investigation.

5. Conclusion and Suggested Policies

This study examined the long-run associations between CO_2 emissions and economic growth, urbanization, international tourism, industrialization, renewable energy consumption, agricultural value added, and forest area in Pakistan, Bangladesh, India, and Sri Lanka. Annual observations covering 1990–2021 were drawn from the World Development Indicators. The analysis employed reported panel unit-root tests, cointegration tests, and dynamic ordinary least squares (DOLS) estimation. These methods were used to investigate relationships among the included economic, demographic, energy-related, and land-use variables. However, interpreting long-run estimates depends on confirming that the underlying integration properties and model assumptions are appropriately satisfied.

The DOLS results indicate positive, statistically significant associations between urbanization, tourism, and agricultural value added and CO_2 emissions. Conversely, renewable energy consumption and forest area are negatively and significantly associated with emissions in the reported model. Economic growth and industrialization have positive but statistically insignificant coefficients; therefore, their estimated effects should not be described as established determinants of emissions in this sample. These findings suggest that energy-related urban and tourism activity, agricultural production conditions, renewable energy use, and forest resources are relevant considerations for environmental policy in the selected South Asian economies. However, the estimates represent conditional statistical associations and do not identify the causal effect of individual interventions. The conclusions also apply only to the four included countries and should not be generalized to all South Asian economies without additional evidence. In addition, differences in the level tests reported for some variables require verification before the econometric specification can be regarded as fully supported.

Policy Recommendations

The findings provide a basis for discussing policies that address environmental pressure while maintaining economic development. Because the significant coefficients concern urbanization, tourism, agricultural value added, renewable energy use, and forest area, the principal recommendations focus on those areas. In contrast, recommendations on economic growth and industrialization should be framed as broader sustainability considerations rather than direct consequences of statistically significant estimates. The following proposals are therefore linked to the reported associations, while recognizing that the study does not estimate the effects of particular policy instruments.

- Economic development policies should place greater emphasis on energy efficiency, cleaner production, and the environmental quality of growth, rather than focusing solely on the expansion of output. In addition, public and private investment can target technologies and infrastructure that reduce reliance on carbon-intensive energy sources. However, because the estimated coefficient for economic growth is statistically insignificant, these proposals are

informed by broader sustainability objectives rather than by a demonstrated direct effect of growth in the present model.

- Although the estimated association between economic growth and CO_2 emissions is not statistically significant, policymakers should continue monitoring the environmental consequences of changes in production and consumption. Similarly, investment in energy-efficient technologies and cleaner energy systems may support development objectives without increasing dependence on fossil fuels. Further empirical work could examine whether differences in income levels, energy composition, or economic structure help explain the absence of a significant pooled growth coefficient.
- Urban planning should emphasize reliable public transport, energy-efficient buildings, protection of green areas, and coordinated land-use management. Compact and walkable neighborhoods may help reduce some transport demands, while better building standards can improve the efficiency of growing urban infrastructure. Because urbanization has a positive and significant association with emissions in the reported model, these measures are relevant to the environmental challenges accompanying urban expansion. However, the present estimates do not quantify the separate effects of individual planning interventions.
- Industrial policy should encourage cleaner technologies, improved energy management, and compliance with environmental standards. In addition, support for resource-efficient production may help firms adapt to sustainability requirements while maintaining economic activity. However, the estimated industrialization coefficient is statistically insignificant in this study. Therefore, these recommendations should not be presented as responses to a demonstrated positive industrialization effect, but as preventive and longer-term measures consistent with sustainable production.
- Tourism policy should encourage lower-emission transport options, efficient energy use in accommodation, responsible land development, and the protection of sensitive destinations. Similarly, managing visitor concentrations and waste can reduce pressure on local infrastructure and ecosystems. The positive and significant tourism coefficient supports attention to the sector's environmental implications. However, the study does not distinguish emissions by travel mode or tourism facility type, so the effectiveness of specific measures requires further assessment.
- Governments should encourage investment in renewable energy through stable regulations, appropriate financial incentives, and improved energy infrastructure. In addition, measures that help integrate renewable energy into wider energy systems may support more sustainable development. The negative and significant renewable energy coefficient provides an empirical basis for prioritizing this area in policy discussion. Similarly, forest conservation and sustainable land management warrant attention because forest area is negatively associated with CO_2 emissions in the reported model. Agricultural policy can also encourage efficient energy and input use, given the positive coefficient for agricultural value added. Clear objectives and monitoring arrangements are important, although the effects of individual programmes are not estimated here.

Ethical Statement: This study analyzes secondary, country-level data obtained from the World Development Indicators. It does not report collecting information from human participants or conducting experiments involving human subjects.

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