Ridwan, Mohammad et al.

Article

Investigating the environmental Kuznets curve hypothesis with urbanization, industrialization, and service sector for six South Asian Countries: Fresh evidence from Driscoll Kraay standard error

Research in Globalization

Provided in Cooperation with:
Elsevier

Suggested Citation: Ridwan, Mohammad et al. (2024) : Investigating the environmental Kuznets curve hypothesis with urbanization, industrialization, and service sector for six South Asian Countries: Fresh evidence from Driscoll Kraay standard error, Research in Globalization, ISSN 2590-051X, Elsevier, Amsterdam, Vol. 8, pp. 1-13, https://doi.org/10.1016/j.resglo.2024.100223

Research in Globalization 8 (2024) 100223

Contents lists available at ScienceDirect

Research in Globalization

journal homepage: www.sciencedirect.com/journal/research-in-globalization

Investigating the environmental Kuznets curve hypothesis with urbanization, industrialization, and service sector for six South Asian Countries: Fresh evidence from Driscoll Kraay standard error

Mohammad Ridwan [a], Afrida Jinnurain Urbee [a], Liton Chandra Voumik [a,b], Mihir Kumar Das [c], Mamunur Rashid [d], Miguel Angel Esquivias [e,*]

[a] *Department of Economics, Noakhali Science and Technology University, Noakhali, 3814, Bangladesh*
[b] *Central Queensland University, 3000, Australia*
[c] *Business and Enterprise, QA Higher Education, London, UK*
[d] *Department of Information Technology, School of Business & Technology, Emporia State University, Emporia, KS, USA*
[e] *Department of Economics, Faculty of Economics and Business, Airlangga University, Surabaya 60268, Indonesia*

ARTICLE INFO

Keywords:
Driscoll-Kraay
CO_2 Emissions
Environmental Degradation
EKC
Sustainable Economic Growth
Sustainable urbanization

ABSTRACT

South Asia is the most polluted region in the world and is struggling to deal with the effects of growing CO_2 emissions and the ecological impact it has left. The region needs to identify the variables that are most effective in reducing pollution in order to achieve long-term sustainable growth. The current study aims to investigate the environmental impacts of the current and projected urbanization rate, the service sector, and the availability of natural resources to test the environmental Kuznets-curve (EKC) theory in six South Asian countries (SAARC). With cross-sectional dependence present, this research examines panel data from 1972 to 2021 using the newly developed Driscoll Kraay Standard Error (DKSE) approach. To check the robustness of DKSE estimation, the study employs a novel Cross Sectional Autoregressive Distributive Lag (CS-ARDL) method. The results of DKSE show that GDP significantly minimizes CO_2 emissions in both the short and long run. At the same time, GDP^2, urbanization, and the service sector increase CO_2 emissions in the South Asian region. The DKSE estimator also shows that industrialization and abundant natural resources have insignificant impacts on CO_2 emissions. Inconsistent with the EKC hypothesis, the findings show that higher economic growth leads to increased environmental pollution and CO_2 levels. Meanwhile, the CS-ARDL analysis found that GDP and industrialization reduce CO_2 emissions, while urbanization, GDP^2, and natural resource availability increase CO_2 emissions. This research emphasizes the need for establishing appropriate industrialization and urbanization strategies and promoting cleaner energy adoption to reduce CO_2 emissions.

1. Introduction

The South Asian Association for Regional Cooperation (SAARC) countries have transformed and advanced significantly as a result of economic growth, urbanization, industrialization, abundant natural resources, and the flourishing service sectors. Our research aims to investigate whether such progress affects carbon dioxide (CO_2) emissions. Environmental degradation is a pressing issue as it affects not only the economy but also the public health (Raihan et al., 2022). The primary cause of environmental degradation is the rising CO_2 emissions globally from increasing energy use (Voumik et al., 2024). Worldwide energy usage was estimated to rise by 2.1 % in 2017, up from 0.9 % in 2016 to 1.1 % during the previous five years (IEA, 2017). In 1990, approximately 20,625,273 kilotons of CO_2 were emitted into the atmosphere, while by 2019, this amount had risen to roughly 34,344,006 kilotons (World Bank, 2020). This trend has driven environmental and climate changes (Rahman, 2017). UN research (2017) suggests that the objectives of the 2015 Paris Agreement to reduce global disasters to pre-industrial levels may not be attained unless there is a significant reduction in CO_2 emissions, below 2 °C and ultimately below 1.5 °C. The impact of not being able to reach the carbon reduction goal will result in severe social and economic consequences.

* Corresponding author.
E-mail addresses: ridwan1213@student.nstu.edu.bd (M. Ridwan), afrida.econ@nstu.edu.bd (A.J. Urbee), l.voumik@cqu.edu.au (L.C. Voumik), miguel@feb.unair.ac.id (M.A. Esquivias).

https://doi.org/10.1016/j.resglo.2024.100223
Received 4 December 2023; Received in revised form 24 March 2024; Accepted 1 May 2024
Available online 9 May 2024

The South Asian region is impacted by climate change in multiple ways, as it is home to a diverse range of ecological zones. The region's CO_2 emissions continue to increase, with India and Pakistan being the most significant contributors (Gunarathne et al. 2020). This trend is driven by economic factors, including energy use, industrialization, urbanization, globalization, and transportation (Bakhsh et al., 2017; Gupta & Garg, 2020; Nocera et al., 2012; Wang et al., 2020). The consequences of environmental changes in the region include global warming, altered rainfall patterns, rising sea levels, and more frequent cyclones and floods (Chauhan et al., 2020). These changes may also affect the region's geophysics and demographics, posing threats to the safety of its billions of residents (Hasnat et al., 2018). The study of development and environmental economics highlights the importance determining the contributors of CO_2 emissions.

The Environmental Kuznets Curve (EKC) hypothesis proposes a relationship between environmental pollution and GDP per capita, which was first observed by Kuznets (Kuznets, 1963, 1955). At the early stages of economic growth, an economy tends to produce more pollution and degrade the environment. As it matures, this trend reverses, forming an inverse U-shaped pattern (Grossman & Krueger, 1991). This concept is widely used to explain the connection between income and pollution (Chen et al., 2019). Policymakers and academics have been concerned about this relationship in recent years. Grossman and Krueger (Grossman & Krueger, 1991) demonstrated that environmental quality tends to decrease during the initial stages of economic expansion in a country and improve as the country's financial situation improves. Studies on energy and the environment in Asia have provided much empirical evidence for EKC. The SAARC region economy and population have been growing rapidly (Rehman & Rashid, 2017). Despite focusing on economic growth, several member countries, such as Bangladesh, India, Pakistan, and Nepal, have embraced the Kyoto Protocol's objective of limiting CO_2 emissions. However, the increasing energy consumption in SAARC nations, fueled by rapid economic growth and a surging population, has offset these efforts. Since 2000, energy consumption in South Asia has risen by more than 50 % (World Bank Blogs, 2022). Additionally, coal as a major energy source in the region contributes significantly to the increased CO_2 emissions (Akhmat, 2014). With the economic shift from low to middle-income status, SAARC countries must assess the relationship between economic development, energy consumption, and pollution. For example, despite the growth, financial resources to improve environmental quality may be limited for adopting sustainable environmental policies as they often require contemporary technologies, renewable energy sources, green urban planning concepts, and eco-friendly industrialization practices.

Countries in the SAARC region are predicted to remain the primary users of nonrenewable energy to fuel their rapid economic expansion and consequently the biggest carbon emitters among emerging economies (Ul-Haq, 2020). Analysts predict that energy consumption will continue to rise in SAARC economies in the coming decades along with the environmental challenges. In particular, India, Bangladesh, Sri Lanka, and Pakistan have shown significant economic growth, as well as a substantial increase in CO_2 emissions. Aside from industrial growth, this increase has been driven by a variety of factors, including a rapidly growing population (Rahman et al., 2020). These countries must allocate much spending on energy imports to support rapid economic growth since they have limited sources of alternative energy. This makes them vulnerable to fluctuations in the prices of oil, which can impact their financial and political stability. These factors underscore the complexity of the decision-making regarding energy, economic growth, and sustainable development. Consequently, it is imperative to investigate the correlation between GDP growth and CO_2 emissions in the SAARC economies.

In addition, industrialization, urbanization, and services have increased rapidly in SAARC countries in recent decades. Industrialization can have negative impacts on environmental quality. It increases resource consumption to maintain production, pushing aside environmental concerns (Liu & Bae, 2018), depletes mineral resources, negatively affecting population well-being and natural resources (Rahman & Majumder, 2020), and degrades air, water, and land quality (Li & Lin, 2015). Likewise, large urban populations may result in increased energy demand, transportation pollution, waste disposal, and CO_2 emissions. South Asia witnessed a 130 million increase in urban population between 2001 and 2011, with an additional 250 million expected by 2030, potentially resulting in a surge in CO_2 emissions (World Bank, 2020). However, as proposed by the compact city theory, the provision of public infrastructure, such as water supply, waste facilities, and transportation systems, may increase environmental quality (Hao & Cho, 2022). In other words, implementing environmentally friendly industrial policies and embracing green urban concepts could significantly benefit the region's ecosystem. Urbanization and industrialization may lead to lower CO_2 emissions, as cities offer opportunities for more efficient transportation systems, stricter environmental policies, economies of scale in energy use, and the adoption of cleaner technologies. Nonetheless, further research is necessary to explore the interconnections between urbanization, industrialization, and the environment in the SAARC region. Fig. 1 illustrates the relationship between CO2 emissions (lnCO2) and three variables: Urbanization, GDP (lnGDP), and resource rents (RES) in SAARC (1972 to 2021), with the connection between CO2 and GDP and urbanization showing a positive correlation.

The overarching goal of our study is to provide insight into how CO_2 emissions are attributed to urbanization, economic progress, industrialization, service, and natural resource use within the context of the SAARC region. This investigation aims to scrutinize the presence of the EKC by applying several novel estimators as the DKSE and the CS-ARDL to the SAARC nations. The increasing GDP, reliance on natural resources, urbanization, and industrialization in the SAARC region may have severe environmental consequences (Waqih & Ullah, 2019; Rani, 2022). Therefore, it is crucial to understand the factors contributing to environmental degradation and find more sustainable ways of managing the environment, energy use, urbanization, industrialization, and economic development. The SAARC nations share deep connections through trade, tourism, faith, and culture. Recognizing this interdependence, our research employs the CSD test to analyze the complex dynamics within this interconnected framework. While previous assessments may have overlooked these interconnected issues (Waqih & Ullah, 2019; Rani, 2022; Kiani, 2022), our study aims to address them comprehensively. In addition to the CSD test, we utilize advanced methodologies such as the 2nd generation unit root test and the Westerland cointegration approach to provide a robust analysis of the relationship between the variables. Furthermore, we employ DKSE estimation to examine the long-term interactions between these variables, offering a refined understanding of the dynamics at play within the SAARC region. Through these rigorous analytical techniques, we aim to unveil the relationships underlying the socio-economic landscape of the SAARC nations.

This study contributes to the literature of EKC in several ways. First, we provide new evidence on the EKC hypothesis in the context of the SAARC countries by applying DKSE and the CS-ARDL approach. This technique allows for a more accurate estimation of the EKC model, reducing potential sources of bias. Second, we approximate the economic transformation experienced by SAARC economies by including the role of industrialization, service sector growth, and urbanization. Few studies have looked into the impact of secondary and tertiary activities on environmental quality in the SAARC region (Kiani, 2022). Urbanization rates in SAARC countries have increased over time, together with industrialization, economic growth, and an increase in the service sector. Such expansion is likely linked to a spike in energy demand, resulting in CO_2 emissions. Third, we incorporate the role of natural resource rents into the model, an aspect that has been overlooked in earlier studies (Rehman & Rashid, 2017; Akhmat, 2014; Rahman et al., 2020; World Bank, 2020). While natural resource rents

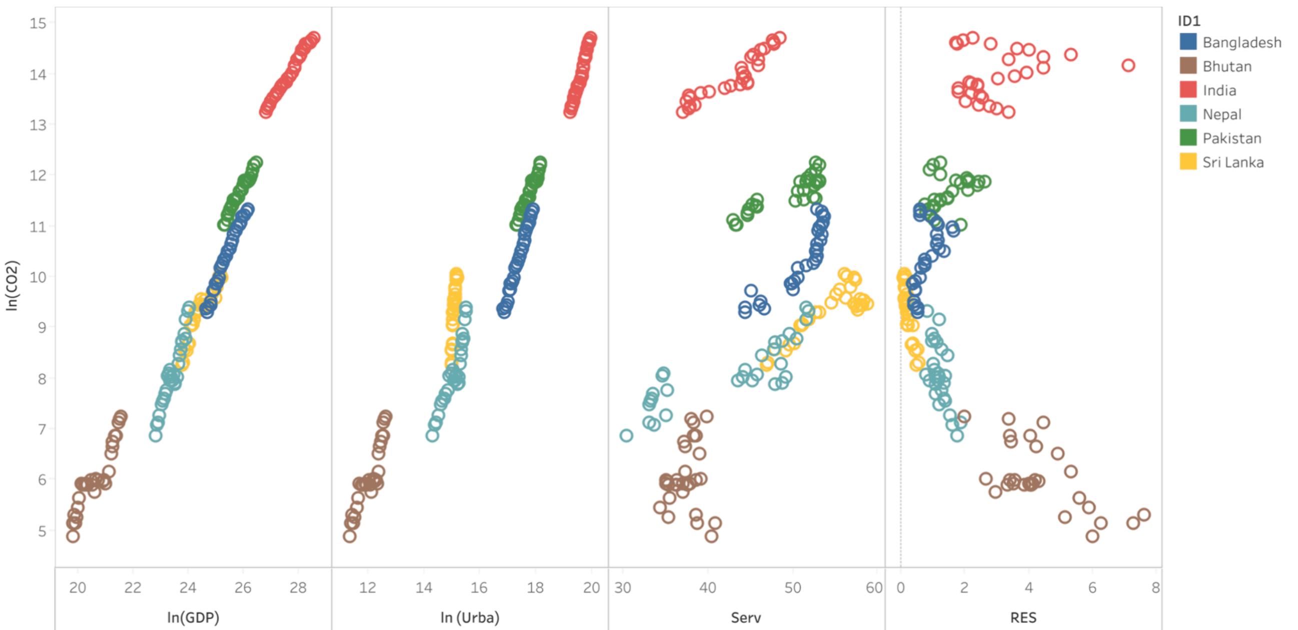

Fig. 1. CO_2 emissions ($lnCO_2$), Urbanization (ln total urban population), GDP (lnGDP), resources rents (RES, percentage of GDP) SAARC (1972 to 2021).

can provide opportunities for environmental conservation and sustainable development, they can also pose significant challenges if not managed carefully. Effective governance, transparent management practices, and strategic investments in environmental protection are essential to mitigate the negative impacts of resource exploitation and ensure long-term environmental sustainability. Fourth, while numerous studies have been conducted in the individual countries, such as India (Gopakumar et al., 2022), Pakistan (Bakhsh et al., 2017; Zhang et al., 2017), Bangladesh (Rahman, 2021), and Sri Lanka (Gunarathne et al., 2020), fewer studies have examined the SAARC region as a whole in a model as ours, despite its high level of interrelation (Rehman & Rashid, 2017; Akhmat, 2014; Rahman et al., 2020; World Bank, 2020; Waqih & Ullah, 2019).

The literature on EKC and the research gap as it pertains to the SAARC countries are summarized in Section 2 of this article. Section 3 outlines the data, conceptual, and empirical contexts. Section 4 presents the results of the experiments. Section 5 discusses the findings. Sections 6 and 7 respectively outline the conclusions and policy implications. Section 8 describes the limitations and suggestions for further study.

2. Literature Review

The EKC hypothesis is a well-known principle in environmental economics, which posits that environmental degradation initially worsens and then improves as the economy grows (Kuznets, 1955). This idea has been extensively examined and debated since its introduction in the 1990 s, with most studies validating the EKC theory. Waqih et al. (2019) observed that EKC persisted in the short run in the SAARC area, but they could not validate its long-term existence. Rani et al. (2022) ascertained the influence of remittances and nonrenewable energies on the environment in the SAARC region and supported the EKC theory in the SAARC area. Similarly, Rehman and Rashid (2017) scrutinized the association between energy use, economic expansion, and environmental damage in the SAARC region. Adopting the DOLS and FMOLS approaches, they detected the presence of EKC throughout the SAARC region. Additionally, Kiani et al. (2022) conducted a study in the ASEAN and SAARC regions and confirmed the EKC hypothesis in both areas. Several studies have used time series data to confirm the existence of the EKC hypothesis. For instance, using the quantile regression method, Purwono et al. (2024) examined the EKC hypothesis in a sample of 77 countries from 2008 to 2019 and found evidence of its existence. Similarly, Gopakumar et al. (2022) analyzed the validity of the EKC in India from 1991 to 2018 using the ARDL method and confirmed the theory. Zhang et al. (2017) investigated the prevalence of the EKC in Pakistan from 1970 to 2012 using the ARDL bound testing method, also confirming its validity. Likewise, Ali et al. (2021) confirmed the EKC hypothesis in Pakistan from 1975 to 2014 using the ARDL estimation method.

Destek and Sinha (2020) and Muhammad et al. (2020) used the FMOLS and two-stage least squares regressions approaches, respectively, to analyze the relationship between economic growth and CO_2 emissions. The results supported the U-shaped association predicted by the EKC theory in high- and upper-middle-income economies. Sarkodie and Ozturk (2020) also found evidence supporting the EKC theory in Kenya using the ARDL approach. Similarly, Suki et al. (2020) found an inverse U-shaped relationship between the economy and environmental pollution in the Malaysian economy. The majority of research also agrees that the EKC exists in high-income and upper-middle-income countries such as Canada (Hamit-Haggar, 2012), the United States (Plassmann & Khanna, 2006), Turkey (Bölük & Mert, 2015), and Malaysia (Lau et al., 2014).

Nonetheless, several other studies fail to support the EKC theory. In their analysis of SAARC nations, Yousef et al. (2016) used both closed and open economy models and the FMOLS approach with panel data from 1972 to 2015, concluding that there is no evidence of EKC in the region. Firoj et al. (2022) surveyed Bangladesh using the ARDL method and data from 1986 to 2018, and their results also refuted the presence of EKC. Itoo and Ali (2023) conducted a study in India using the EKC framework, ARDL, FMOLS, and DOLS estimates, and found no evidence of the theory. Mehmood et al. (2022) investigated the influence of tourism and sustainable energy on EKC in South Asian nations, finding no evidence of EKC in Nepal and Sri Lanka but confirming its existence in India and Pakistan. Finally, Yilanci and Pata (2020) used the ARDL estimation method to determine that the EKC hypothesis does not exist in China.

Meanwhile, urbanization and CO_2 emissions linkage has been studied across regions. Anser et al. (2020) examined the impact of urbanization on carbon emissions in the SAARC region between 1994 and 2013. The researchers utilized the STIRPAT framework and DKSE estimator to assess the relationship. Their results showed a U-shaped connection between the two, with emissions initially decreasing as urbanization increased but eventually rising beyond a certain point. From 1996 to 2015, Mehmood (2021) revealed that urbanization improves air quality in the SAARC region. From 1982 to 2013, Azam and Khan (2016) examined the effects of urbanization on environmental deterioration in Bangladesh, India, Sri Lanka, and Pakistan, using the least squares approach. The outcomes demonstrated a positive linkage between urbanization and environmental destruction in Sri Lanka and Pakistan but a negative association in Bangladesh and India.

In addition, Murshed and Saadat (2018) investigated the relationship between urbanization and climate change in Bangladesh from 1991 to 2016 applying the DOLS and FMOLS methods. The study revealed that when urbanization intensified, CO_2 emissions dropped but rose at a certain threshold. Between 2000 and 2016, Gieratowska et al. (2022) examined the influence of sustainable energy and urbanization on CO_2 emissions across 163 countries, revealing an inverse U-shaped relationship between the two variables. Similarly, Shahbaz et al. (2016) analyzed the relationship between urbanization and CO_2 emissions in Malaysia from 1970 to 2011. They found a U-shaped correlation between the two variables using the ARDL cointegration technique. Meanwhile, Al-Mulali et al. (2013) examined the relationship between energy consumption, urbanization, and CO_2 emissions in MENA countries between 1980 and 2009. The study used the Pedroni cointegration test and the DOLS technique to show a strong, positive long-term correlation between urbanization and CO_2 emissions. In the context of Indonesia, Ahmed et al. (2019) investigated the relationship between urbanization and CO_2 emissions between 1971 and 2014. Their study revealed a nonlinear connection between the two variables, with an inverted U-shaped curve. Urbanization initially had a positive effect on CO_2 emissions, but this relationship reversed at a certain point.

Similar to urbanization, industrialization has brought many benefits to modern civilizations, but it has also led to increased CO_2 emissions. Several studies have examined the relationship between industrialization and CO_2 emissions. Ahmad et al. (2013) and Siddique and Abubakar (2022) conducted separate studies on the impact of population and industrial expansion on CO_2 emissions and the environment in the SAARC region. Ahmad et al. (2013) found that industrialization and population growth were the main drivers of CO_2 emissions in the region, while Siddique and Abubakar (2022) discovered a two-way causal linkage between industrialization and CO_2 emissions. Both studies were conducted in the SAARC region between 1980 and 2016.

Additionally, Mentel et al. (2022) examined the correlation between Sub-Saharan Africa's industrialization and emissions of CO_2 using data from 2000 to 2015. Using a two-step GMM estimator, the study found a clear linkage between CO_2 emissions and the value added by an industry to GDP. From 1975 to 2010, Shahbaz (2014) evaluated the connection between industrialization, energy usage, and CO_2 emissions in Bangladesh. Using an ARDL bounds testing strategy, this research discovered that energy consumption exacerbated environmental deterioration and that the interaction between industrialization and emissions of CO_2 followed a nonlinear, inverted U-shape. Also using ARDL estimation, Ullah (2020) assessed Pakistan's industrialization and CO_2 emissions between 1980 and 2018. The findings point to a positive correlation between the size of the industry's contribution to GDP and subsequent increases in CO_2 emissions. The research also showed that atmospheric deterioration was slowed by economic advancement and urbanization. In addition, Mahmood et al. (2020) used the ARDL model to investigate the link between industrialization and CO_2 emissions in Saudi Arabia from 1968 to 2014. The data demonstrated that industrialization resulted in a substantial rise in environmental damage, pointing out that stricter industrial rules were needed to reduce CO_2 emissions. From 1999 to 2020, Raihan and Tuspekova (2022) inspected the linkage between energy usage, industrialization, and CO_2 in Russia. The research adopted several estimation approaches, such as ARDL, DOLS, and FMOLS, finding that industrialization causes a long-term, significant increase in CO_2 emissions.

As for the service sector, numerous studies have examined the relationship between the value added by the service sector and CO_2 emissions. Hashmi et al. (2020) investigated the nonlinear connection between Pakistan's services sector and CO_2 emissions, analyzing data from 1971 to 2014 using the ARDL method. Their findings revealed an inverted U-shaped relationship between the two variables. Samarkand (2017) studied the link between service value addition, technical innovation, and CO_2 emissions in the Saudi Arabian EKC framework. The findings showed that service sector value addition is the primary contributor to the rapid increase in CO_2 emissions. Murshed (2020) studied the impact of service value addition on CO_2 emissions in 12 OPEC countries from 1992 to 2015. They used a spatial panel technique and found an inverted U-shaped relationship between the two variables. Alam (2015) investigated the impact of industry, agriculture, and service sectors on CO_2 emissions in South Asian countries between 1972 and 2010. Their findings revealed that the industrial and service sectors have a significant positive relationship with CO_2 emissions, while the agricultural sector exhibits an inverse association.

In sum, our review of previous literature revealed a scarcity of studies that specifically investigate the EKC hypothesis for South Asia while considering the effects of urbanization, industrialization, and service sector development. Although some studies have examined the EKC in emerging countries, their scope is limited and the effects of different economic sectors have not been included. South Asia is a rapidly developing region with unique financial and environmental characteristics, making it an ideal case for testing the EKC hypothesis. Moreover, our research employs the DKSE method, which has not been widely used in previous EKC research. This method allows for efficient estimation of panel data models with unobserved heterogeneity, thereby adding to the methodological advancement of the field. Consequently, addressing this literature gap may further our knowledge of the interaction between economic progress and environmental deterioration in South Asia and give significant policy implications for the region's sustainable growth.

3. Methodology

This study utilizes current data and multiple inferential econometric approaches to evaluate the linkage between study variables. Fig. 2 depicts the steps and overview of econometric analysis.

3.1. Data

By using the Driscoll Kray standard error method established by Driscoll and Kraay (1998), the present investigation empirically explores the existence of the EKC in South Asian economies, taking into account the influence of urbanization and industrialization on CO_2 emission. This study adopts World Development Indicators (WDI) data from 1972 to 2021 in the South Asian region. This collected data is included in the dataset. In this specific research, CO_2 emissions are the dependent variable, and the explanatory factors include variables such as GDP, GDP^2, urbanization, industrialization, service, and abundance of natural resources. The last phase is transforming the study variable into logarithmic form, which is performed to ensure that the data have a normal distribution. Table 1 contains the variables and their corresponding logarithmic conditions, units of measure, and data sources.

Table 2 contains the variables LCO_2, LGDP, $LGDP^2$, LURBA, LINDUS, LSERV, and LRES. The variables are listed in the first column, and each variable's sample size (N) is listed in the second column. This is the number of available observations or data points for the variable. The mean or average value for each variable is shown in the third column. The mean is a summary statistic that indicates the prevailing pattern of the data. In the fourth column, the standard deviation (sd) for each variable is shown. The standard deviation quantifies the dispersion or spread of the data. It indicates the deviation of the data values from the mean. The fifth and sixth columns list each variable's lowest and

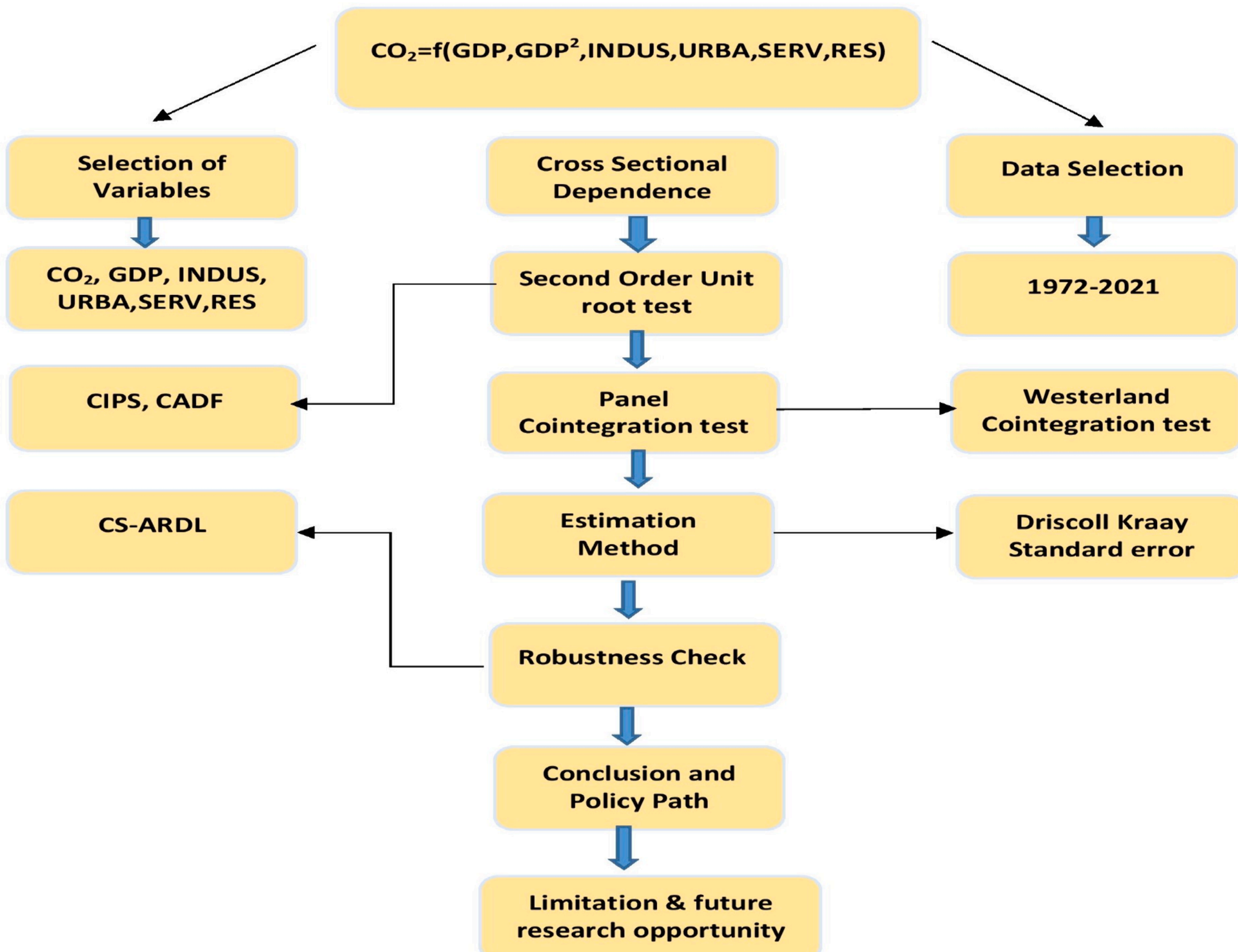

Fig. 2. Flow chart of econometric approach.

Table 1
Description of study variables.

Variable Name	Signifier	Measurement
CO_2 emission	LCO_2	CO_2emissions (kt)
GDP	LGDP	GDP (constant 2015 US$)
GDP square	$LGDP^2$	Square of GDP (constant 2015 US$)
Urbanization	LURBA	Urban population (% of the total population)
Industrialization	LINDUS	Industry (including construction), value added (% of GDP)
Service	LSERV	Services, value added (% of GDP)
Resource	LRES	Total natural resources rents (% of GDP)

Table 2
Summary Statistics.

Variables	N	mean	sd	min	max
LCO_2	303	9.391	2.712	4.868	14.71
LGDP	312	24.12	2.216	18.91	28.62
$LGDP^2$	312	586.8	105.9	357.7	819.3
LURBA	343	15.16	2.883	9.746	19.99
LINDUS	304	3.075	0.370	1.802	3.809
LSERV	304	3.782	0.245	2.960	4.356
LRES	320	1.769	2.134	0.00258	16.41

maximum values. These numbers indicate this variable's maximum and minimum values in the data collection. Thus, Table 2 includes descriptive statistics for seven variables in the research, summarizing the data's distribution and variability. The log of GDP^2 has the highest value in the summary statistics, while the log of RES has the lowest. As opposed to the other standard variables, whose standard deviation ranges between 0.245 and 2.883, the GDP^2 is judged excessively big.

Table 3
Findings of CSD test.

Variable	Test Statistics (P-value)
LCO_2	13.716***
LGDP	12.253***
$LGDP^2$	−12.057***
LURBA	15.026***
LINDUS	24.826***
LSERV	13.686***
LRES	5.64***

Asterisk sign *** was utilized for a 1% significance level.

3.2. Theoretical framework

The EKC theory is an extension of Simon Kuznets's Curve hypothesis, suggesting a nonlinear relationship between economic advancement and environmental quality (Kuznets, 1955). Initially proposed by Grossman and Krueger (1991), it asserts a nonlinear link between economic expansion and environmental quality, particularly regarding CO_2 emissions. Studies have examined the EKC hypothesis's reliability using various methods, focusing primarily on CO_2 emissions as a measure of environmental quality (Grossman & Krueger, 1991). The hypothesis suggests a trade-off between economic development and ecological deterioration in the early stages, with CO_2 emissions initially increasing. However, beyond a certain growth rate, continued economic expansion is expected to lower CO_2 emissions, resulting in an inverted U-shaped relationship (Grossman & Krueger, 1991). This study aims to explore the existence of the EKC hypothesis in South Asian nations, considering not only economic growth but also the impacts of industrialization, urbanization, the service sector, and natural resources on CO_2 emissions. The subsequent step involves incorporating pertinent explanatory variables and CO_2 emissions into an equation.

The subsequent step is to include our pertinent explanatory variables and CO_2 emissions in an equation.

To describe the investigation mentioned above, the following Eq. (1) is constructed:

$$EnvironmentalDegradation = f(GDP, GDP^2, URBA, INDUS, SERV, RES) \tag{1}$$

The preceding Eq. (1) can be rewritten in EKC format as Eq. (2):

$$ED_{i,t} = \beta_0 + \beta_1 GDP_{i,t} + \beta_2 GDP^2_{i,t} + \beta_3 M_{i,t} + \varepsilon_{i,t} \tag{2}$$

Here, ED, GDP & GDP^2 denote environmental degradation, representing economic growth and its square, and variable 'M' represents other variables influencing ecological degradation. Moreover, 'ε' stands for the error term.

Eq. (3) is an extensive form of the Equation mentioned above, as shown below:

$$\begin{aligned} CO_{2i,t} = \beta_0 + \beta_1 GDP_{i,t} + \beta_2 GDP^2_{i,t} + \beta_3 URBA_{i,t} + \beta_4 INDUS_{i,t} \\ + \beta_5 SERV_{i,t} + \beta_6 RES_{i,t} + \varepsilon_{i,t} \end{aligned} \tag{3}$$

Here, CO_2 represents carbon dioxide and is used as a proxy for environmental degradation, INDUS stands for industrialization, URBA denotes urbanization, SERV represents service, RES stands for resource, and GDP& GDP^2 are defined before.

The logarithms of the variables are displayed in Eq. (4). The logarithmic transformation can modify the distribution to be more symmetrical and in line with a normal distribution. This might be helpful since the normality of distribution is a presumption of many statistical tests. To improve the accuracy and interpretability of statistical tests, skewed variables might be transformed into normally distributed variables. The logarithmic transformation can also be employed to stabilize the variability of a variable, making the analysis more robust against outlying values. Thus, Eq. (4) is written as follows:

$$\begin{aligned} LCO_{2i,t} = \beta_0 + \beta_1 LGDP_{i,t} + \beta_2 LGDP^2_{i,t} + \beta_3 LURBA_{i,t} + \beta_4 LINDUS_{i,t} \\ + \beta_5 LSERV_{i,t} + \beta_6 LRES_{i,t} + \varepsilon_{i,t} \end{aligned} \tag{4}$$

In this study, coefficients β_0 to β_6 represent coefficients of the variables, and i & t represent cross-section and time indicators.

Therefore, the EKC serves as a crucial theoretical methodology in understanding the intricate relationship between economic development and environmental degradation. By positing an initial rise in environmental impact with economic growth, followed by a subsequent decline, the EKC offers valuable insights for policymakers. This framework guides the formulation of strategies that balance economic expansion with environmental preservation, aiding in identifying optimal development paths. Moreover, the EKC encourages the prioritization of environmental policies based on the stage of economic development, informing decisions ranging from pollution control in early stages to sustainable development practices in later phases. It also plays a pivotal role in fostering public awareness, highlighting the need for environmentally conscious policies and procedures as integral components of sustainable economic growth.

3.3. Econometric methodology

The research data were collected utilizing panel setups. Because the frequency of T was greater than that of N, a panel cointegration analysis was conducted. We have information from eight countries spanning over fifty years. If T > N, conventional panel data approaches such as pooled OLS, fixed effect models, and random effect models cannot be used. These methods are most effective when N > T. This study's primary goal is to assess the effects of industrialization, urbanization, and economic growth on CO_2 emissions. This research examined the nature of the long-term connection using utilization panel cointegration tests from Westerlund (2007) and DKSE (1998). In econometric analysis, DKSE is commonly employed to address cross-sectional dependence and slope heterogeneity. Unlike conventional standard errors, DKSE accounts for correlated errors that may arise across observations, thereby mitigating potential biases and inefficiencies during parameter estimation. Given the potential spatial or temporal correlation between observations, this approach enhances the accuracy of inferences in models where conventional standard errors might produce misleading results. The analysis revealed cross-sectional dependence and slope heterogeneity, and thus, the DKSE was utilized. To ensure robustness, the CS-ARDL approach was also used in South Asian countries between 1972 and 2021. Then, we looked for signs of CSD in panel data. We also ensured that the data remained stationary. Thirdly, we conducted the panel cointegration test. Considering the results of the initial tests, we chose an economic model and estimation method and assessed the long-term interaction between the variables.

3.3.1. Cross-Sectional dependence test

If economic integration rises and other impediments are eliminated, the level of CSD in panel data is predicted to increase. CSD may result in skewed, misleading, and contradictory findings if researchers disregard the problem and treat the cross-sections as isolated (Hoyos et al., 2006). This study analyzes CSD using comprehensive panel data inferential statistics with weakly exogenous variables. The CSD of the data must be confirmed before utilizing the 2nd generation unit root tests. Eq. (5) employed for testing CSD, as shown below:

$$CSD = \sqrt{\frac{2T}{N(N-1)N}\left(\sum_{i=1}^{N-1}\sum_{K=i+1}^{N}\widehat{Corr}_{i,t}\right)} \tag{5}$$

Where $\widehat{Corr}_{i,t}$ is here, there is a pairwise correlation in Equation ().

3.3.2. Panel unit root test

Rauf (2018) suggested using nonparametric and parametric methods to ensure the proper cointegration order for panel data. Over-rejection of Null hypotheses, CSD effects, and heterogeneity are not considered in the 1st generation of panel unit root testing (Choi, 2001). To address this problem, the research employs a Cross-sectional Augmented CIPS and Cross-sectional Augmented Dickey-Fuller (CADF), both 2nd generation panel unit root tests (Pesaran, 2007). The formula used to conduct the CADF test is as follows in Eq. (6):

$$\Delta Y_{it} = \beta_i + \alpha_i y_{i,t-1} + b_i \bar{y}_{t-1} + d_i \Delta \bar{y}_t + \hat{a}\pm'_{it} \tag{6}$$

To account for the lag introduced by Eq. (6), the subsequent Eq. (7) looks like this:

$$\Delta Y_{it} = \beta_i + \alpha_i y_{i,t-1} + b_i \bar{y}_{t-1} + \sum_{j=0}^{p} d_{ij} \Delta \bar{y}_{t-j} + \sum_{j=1}^{p} \varphi_{ij} \Delta y_{i,t-j} + \hat{a}\pm'_{it} \tag{7}$$

In this case, $\bar{y}_{t-j}$ and y_i t-1 represent the average of the accumulated differences between the first sections of the cross-sections and the units, respectively, after a lag of t. After the CADF data are calculated, the CIPS test statistics are calculated.

To see the findings of the CIPS test statistics, see Eq. (8) given as follows:

$$CIPS = \frac{1}{N}\sum_{i=1}^{N} t_i(N,T) \tag{8}$$

When both variables and panels show signs of heterogeneity and CSD, it is best to utilize 2nd generation panel unit root tests, which offer precise estimates. Tables 4 and 5 exhibit the results of the second-generation panel unit root (CIPS and CADF) tests dealing with the CSD issue, showing that the null hypothesis of CSD was rejected for all variables at the 1 % significance level. CIPS unit root test findings reject the null idea for all variables and approve the alternative hypothesis. In general, determining a unit root exists among the variables in an empirical study might provide inaccurate findings. Consequently, the stationarity of variables is determined before the empirical estimate.

1.3.3. Panel cointegration test

To test for long-term cointegration between the variables after data stationarity, this research will implement a 2nd generation panel cointegration test. Compared to first-generation panel-cointegration techniques, this method offers more reliable and consistent estimates of cointegration. The Westerlund cointegration test (Westerlund, 2007) is stated as follows in its functional form on Eqs. (9) to (12):

$$G_t = \frac{1}{N}\sum_{j=1}^{N}\frac{\Theta_j^f}{SE\left(\Theta_j^f\right)} \tag{9}$$

$$G_a = \frac{1}{N}\sum_{j=1}^{N}\frac{T_j^f}{\Theta_j^f(1)} \tag{10}$$

$$P_t = \frac{\Theta_j^f}{SE(\Theta^f)} \tag{11}$$

$$\Theta^f = \frac{P_a}{T} \tag{12}$$

$\Theta^f = \frac{P_a}{T}$ Shows the ratio of correction yearly.

To analyze the long-term association between variables across all 8 South Asian economies, we first ensure their stationarity using the 2nd generation bootstrap panel cointegration. The new panel cointegration test devised by Westerlund (2007) emphasizes statics that are structural as opposed to residual. The findings demonstrate that these tests have more reliable outcomes and constrained normal distributions. According to Westerlund (2007) and Persyn and Westerlund (2008), the cointegration hypothesis is examined using panel and group mean. Ga, Gt, Pa, and Pt are four test statistics that Westerlund (2007) created utilizing the Error Correction Model. The standard error parameters of the error correction model are used to determine the Gt and Pt. Ga and Pa are determined employing standard errors from Newey and West (1994) that have been adjusted for autocorrelations and heteroskedasticity. The results are presented in two ways, with the outcome accepting the alternative and rejecting the null hypothesis. The 2nd generation test confirms the long-term cointegration of the variables.

Table 4
CIPS unit root test results.

Variables (in the log)	Level		First difference		Order
	Without trend	With trend	Without trend	With trend	
LCO_2	−2.170	−3.197***	−3.639***	−3.636***	I(1)
LGDP	−2.727***	−2.809*	−3.715***	−3.706***	I(1)
$LGDP^2$	−1.633	−2.491**	−2.066	−2.293	I(0)
LURBA	−3.837***	−3.706***	−5.730***	−5.900***	I(0)
LINDUS	−2.886***	−2.774*	−4.839***	−5.038***	I(1)
LSERV	−2.381**	−2.438	−4.984***	−5.232***	I(1)
LRES	−1.026	−2.243	−3.046***	−4.124***	I(1)

Asterisk sign ***, **, &* are utilized for 1%,5%, and 10% significance level.

Table 5
CADF Unit Root Test.

Variables	CADF test					
	At Level			1st differences		
	T-bar	Z-t-tilde-bar	P value	T-bar	Z-t-tilde-bar	P value
LCO_2	−2.485	−1.671	0.47	−3.254	−6.254	0
LGDP	−2.6.6	−1.966	0.025			
$LGDP^2$	−2.041	−0.621	0.267	−3.051	−3.023	0.001
LURBA	−2.333	−1.32	0.093			
LINDUS	−1.173	1.444	0.926	−4.745	−7.053	0
LSERV	−1.458	0.765	0.778	−4.795	−7.173	0
LRES	−1.794	−0.034	0.486	−4.983	−7.62	0

3.3.4. Driscoll Kraay standard Error

The research applied the DKSE (Driscoll & Kraay, 1998) approach. We experimentally evaluate how CO_2 emissions are impacted by economic growth, industrialization, urbanization, the service sector, and natural resources on CO_2 emission in a panel of South Asian nations. Since Driscoll-Kraay standard errors are heteroskedastic, autocorrelation consistent, and resistant to common types of cross-sectional and temporal dependency, they are used when there is cross-sectional dependence (Hoechle, 2007). Moreover, it has been shown that this technique is superior to others, such as the Parks-Kmenta method or the panel-corrected standard errors proposed by Beck and Katz (1995), for models in which the number of cross sections higher than the number of periods (N > T). Estimates are constructed using models with fixed effects, which eliminate the impacts of heterogeneity bias by accounting for constant variations across nations (Driscoll & Kraay, 1998; Hoechle, 2007).

The DKSE methodology is a nonparametric method that permits flexibility and comprehensive time dimensions. The covariance estimator is flexible enough to use unbalanced or balanced panel data, accounting for missing values. Therefore, the estimations can resist common cross-sectional and temporal dependency patterns. The DKSE methodology is a nonparametric method that permits flexibility and comprehensive time dimensions. Its covariance estimator is flexible enough to use unbalanced or balanced panel data, accounting for missing values. The DKSE estimation for pooled ordinary least squares assessment can be written as follows in Eq. (13):

$$y_{i,t} = x'_{i,t}\beta + \varepsilon_{i,t}, i = 1,\cdots\cdots, N, t = 1,\cdots.., T \tag{13}$$

Where $x_{i,t}$ is the independent factors (such as GDP growth, industrialization, urbanization, Service provision, and natural resource availability), and $y_{i,t}$ is the scalar dependent variable (CO_2 emissions).

In two stages, the corresponding fixed-effects estimator is constructed. In the first stage, all model variables $Z_{it} \in \{y_{it}, x_{it}\}$ are modified as follows:

In the first stage, all model variables $Z_{it} \in \{y_{it}, x_{it}\}$ are modified as follows in Eq. (14):

$$\widetilde{Z} = Z_{it} - \overline{Z_i} + \overline{\overline{Z}} \tag{14}$$

where, $\overline{Z_i} = T_i^{-1}\sum_{t=t_{i1}}^{T_i} Z_{it}$ and $.\overline{\overline{Z}} = \left(\sum T_i\right)^{-1}\sum_i\sum_t Z_{it}$

Given that the OLS estimator of the within-estimator is shown in Eq. (15):

$$\widetilde{y_{it}} = \widetilde{x_{it}}\Theta + \widetilde{\varepsilon_{it}} \tag{15}$$

The modified regression model in (13) is then estimated in the second stage using pooled OLS estimation.

3.3.5. Robustness Check

This study also applies a novel CS-ARDL approach to verify the results of the Driscoll Kraay estimator. The CS-ARDL technique was devised by Chudik and Pesaran (2015) to observe the long-short-run association between the variables. This approach requires much less time & effort than other estimation methods, such as Pooled Mean Group (PMG), Mean Group (MG), and Augmented Mean Group (AMG) approach. Furthermore, this technique addresses the difficulties of non-stationarity, CSD, mixed-order integration, and Slope Homogeneity. This is because skipping unobserved common components is directly related to generating inaccurate estimate findings. The CS-ARDL may be written in the form of the following Eq. (16):

$$LCO_2 = \alpha_{it} + \sum_{j=1}^{p} \beta_{it} LCO_{2_{i,\ t-j}} + \sum_{j=0}^{p} \varphi_{it} X_{t-j} + \sum_{j=1}^{p} a\overline{Y}_{t-j} + \varepsilon_{it} \tag{16}$$

Where, $\overline{Y}_t = \left(\Delta\overline{LCO2_t X_t'}\right)'$ and $X_{it}' = \left(LGDP_{it}, LGDP_{it}^2, LURBA_{it}, LINDUS_{it}, LSERV_{it}, LRES_{it}\right)'$

4. Empirical findings

4.1. Results of CSD

The results of a CSD test are shown in Table 3 for selected variables. The test was carried out to examine how the cross-section variables were correlated. The p-values and test statistics are provided for each explanatory variable. The p-value, presuming no CSD issue between the variables, reflects the probability of witnessing the test statistics. The null hypothesis of no CSD is rejected, and it is determined that the variables are cross-sectionally dependent if the p-value is less than one of three significance levels (1 %, 5 %, and 10 %). Table 3 shows evidence of a CSD for all study variables at the 1 % level, as demonstrated by the p-values for the tests conducted on cross-sectional variables. Thus, the shock felt in one nation would be felt across the whole panel. As a result, second-generation tests need to be conducted concerning the study's variables.

4.2. Panel unit root test

Table 4 shows the outcomes of the CIPS unit root test. The choice of regression model for further analysis is influenced by whether or not a time series is stationary, and the unit root test is employed to make this determination. Stationary series tend not to return to their mean over time, but non-stationary series do since they contain a unit root. Table 4 is arranged by each variable's level (with & without trend) and first difference (with & without trend), and the rightmost column displays the order of integration (I (0) or I (1)). Based on the results in Table 4, LCO_2, LINDUS, LGDP, LSERV, and LRES are significant at 1 % in both with & without trends at the first difference and become I (1). Besides, LURBA and $LGDP^2$ are assigned to I (0) as they are significant at the level. Thus, CIPS outcomes showed no unit root problem in the data set, and variables showed mixed order of integration. Additionally, the CADF unit root test outcomes are presented in Table 5, and no unit root problem is found in the data set. The findings of CADF are consistent with CIPS and showed that variables had mixed order of integration.

4.3. Panel cointegration test

After verifying that all variables are steady, the next step is determining whether they are cointegrated throughout periods. Table 6 exhibits the outcomes of the cointegration tests performed for this study; these tests were constructed utilizing Westerlund's (2007) technique. We may reject the null hypothesis since the Gt and Ga statistics have statistically significant p-values (less than 10 %). There is statistically significant evidence for two of the four test statistics. The maximum lag lengths are determined using AIC values. The findings of the Westerland cointegration test indicate that the variables under investigation are, in fact, long-run cointegrated.

Table 6
Cointegration Test.

Statistics	Gt	Ga	Pt	Pa
Value	−3.431	−6.539	−4.404	−3.886
Z-value	−1.842	2.291	2.685	2.799
P value	0.01	0.05	0.55	0.75

Software for analysis: STATA.

4.4. Driscoll Kraay standard error

The outcomes of DKSE are presented in Table 7, which arranges the coefficients of each variable, t statistics, standard error, and corresponding p-value. According to the findings of DKSE, the coefficient value of LGDP is −1.1883, which is significant at a 5 % significance level. The coefficient value of LGDP revealed that a 1 % increase in GDP will lower CO_2 emission by 1.1883 %. Additionally, DKSE showed that $LGDP^2$ has a significant positive association with LCO_2 at a 1 % significance level. The findings revealed that a 1 % rise in $LGDP^2$ will increase LCO_2 by 0.0599 %. This positive association indicated that the linkage between economic expansion and CO_2 emission does not hold an inverted U-shaped association. Thus, DKSE estimation demonstrated that the EKC premise does not exist in the South Asian region. Moreover, the coefficient value of LURBA is 0.1186 and highly significant at a 1 % significance level. The significant positive association between LURBA and LCO_2 implied that a 1 % increase in LURBA will increase LCO_2 by 0.1186 %, and vice versa. Furthermore, the coefficients of LSERV showed a significant positive association with LCO_2 and implied that a 1 % increase in LSERV will increase LCO_2 by 0.4594 %. Finally, the DKSE findings showed that LINDUS and LRES have no significant relationship with LCO_2.

4.5. Findings of CS-ARDL

To check the validity of DKSE estimation, we employed a novel CS-ARDL estimation approach. The findings of the CS-ARDL estimation approach are displayed in Table 8. The long-run analysis of CS-ARDL demonstrated that LGDP has a significant negative association with LCO_2 and implied that a 1 % increase in LGDP will lower LCO_2 by 8.788 % in the long run. The coefficient value of LGDP also has a significant negative linkage with LCO_2 in the short run. Thus, this negative association between LGDP and LCO_2 is consistent with the estimation of DKSE. Furthermore, findings of CS-ARDL showed that $LGDP^2$ and LCO_2

Table 7
Findings of Driscoll Kraay's standard error.

Driskoll Kraay fixed affect outcomes				
Dependent variable: CO_2				
Explanatory Variables	Coefficient	Drisc/Kraay Std. Dev	t-Statistics	Probability
LGDP	−1.1883**	0.7694	−2.45	0.021
$LGDP^2$	0.0599***	0.0157	3.8	0.001
LURBA	0.1186***	0.0382	3.11	0.004
LINDUS	−0.0226	0.0802	−0.28	0.78
LSERV	0.4594***	0.1525	3.01	0.005
LRES	0.0619	0.0568	1.09	0.286
Constant	15.9875*	9.2996	1.72	0.097
$F_{Statistics}$	1376.44	Probability	0.0000	
R-squared	0.9845	Root- MSE	0.3309	
Number of Observations: 190		Number of Groups: 7		

Note. Asterisk sign ***, ** &* are utilized for 1%,5%, and 10% significance level,

Table 8
Results of CS-ARDL.

	(1)	(2)
Variables	Long-Run	Short-Run
LGDP	−8.788***(4.47)	−18.48*(10.88)
$LGDP^2$	0.218*(0.122)	0.436**(0.197)
LURBA	1.376*(1.635)	0.857(1.775)
LINDUS	−0.506**(0.283)	−0.580**(0.282)
LSERV	0.270(0.708)	0.448(0.651)
LRES	9.781***(4.827)	15.15(15.20)
Observations		184
R^2		0.471

Asterisk sign ***, ** &* are utilized for 1%,5%, and 10% significance level. Standard deviations are mentioned in brackets.

are positively correlated in both the short and long runs. The result implied that a 1 % increase in $LGDP^2$ will increase LCO_2 by 0.218 % in the long run and 0.436 % in the short run. This positive association between $LGDP^2$ and LCO_2 also aligns with the estimation of DKSE. Therefore, both CS-ARDL and DK estimation methods implied that the EKC premises do not exist in the South Asian region. In addition, the coefficient of LURBA has a significant positive association with LCO_2. This result implied that a 1 % increase in LURBA will increase LCO_2 by 1.376 % in the long run. This positive association between LURBA and LCO_2 is consistent with DKSE estimation. The CS-ARDL estimation found that LINDUS has a significant relationship with LCO_2. The estimation also showed that LRES has a significant impact on LCO_2 in the long run only. In contrast, LSERV has an insignificant linkage with LCO_2.

5. Discussion

In this study, neither the DKSE estimator nor the CS-ARDL method found evidence of the presence of EKC in the South Asian region. This extends the dispute about the validity of the EKC in recent years, in which evidence to support this claim exists in the SAARC region. South Asian nations' capacity to deal with environmental concerns tends to lag behind their fast economic growth. Due to their rapid growth, these economies have not been able to establish effective environmental policies. The absence of legislation and enforcement mechanisms has resulted in extensive ecological deterioration.

The EKC hypothesis also anticipates that technical advancements brought by economic expansion will lessen environmental deterioration. However, the obsolete and energy-intensive equipment utilized in many South Asian nations results in the opposite. Moreover, the EKC hypothesis considers market failure to cause ecological deterioration and predicts that the market will internalize environmental costs as economies improve. The market typically fails to absorb the costs of environmental deterioration in many South Asian nations, placing most of the burden on low-income and marginalized populations.

The EKC theory also fails to recognize the influence of globalization and international trade on environmental conditions. It does not confirm that the rising emissions and environmental degradation are attributable to the expansion of global trade and the exploitation of natural resources in South Asian nations. While several South Asian nations have seen economic growth, most of their populations have not reaped the benefits. This disparity reduces the market's ability to absorb environmental costs, making it harder to solve environmental challenges.

The findings of the study regarding the EKC hypotheses are consistent with several researchers (Yousaf et al., 2016 ; Firoj, 2022; Itoo & Ali, 2023; Akhmat, 2014; Aye & Edoja, 2017; Voumik et al., 2022; Bibi & Jamil, 2021,; Villanthenkodath, 2021, Minlah & Zhang, 2021, Pata & Aydin, 2020, and Purwono et al., 2024). However, the findings of this study contradict many other researchers, such as Rehman and Rashid (2017), Rani (2022), Kiani (2022), Rahman (2021), Gopakumar et al. (2022), Voumik et al. (2022), and Tenaw and Beyene (2021).

This study observed that urbanization has a significant positive correlation with CO_2 emissions. Rapid urbanization in South Asia has led to a surge in CO_2 emissions. There are various reasons why urbanization growth contributes to increasing CO_2 emissions in the South Asian region. First, as cities get more populated, more energy-intensive structures are built, increasing energy usage (Voumik et al., 2024). The energy demand prompts power production, which mainly uses fossil fuels, which drive CO_2 emissions. In addition, the manufacturing of building materials, the deliveries of commodities, and new buildings construction also adds to CO_2 emissions. The same is true for the more intensified use of transportation. As cities expand, there will be more vehicles on the road, hence the CO_2 emissions. The problem is exacerbated by the shortage of adequate public transport in many South Asian cities, which forces residents to depend on their automobiles for mobility.

Moreover, industries in metropolitan areas are expanding. The industry is one of the most significant sources of CO_2 emissions, and as cities grow more industrialized, the emissions increase. Energy-intensive industries like steel and cement production cause a significant rise in CO_2 emissions. Industrialization and urbanization also result in deforestation. Forests are cleaned up for residential development, so CO_2 absorption declines. The findings of this study are in line with past studies, such as by Mahmood et al. (2020), Voumik and Sultana (2022), Anwar et al. (2020), Cheng and Xiaowen (2022), Mignamissi and Djeufack (2022), Lee (2022), and Purwono et al. (2024).

This study also found a significant positive correlation between service sector development and GDP and CO_2 emission. There are several reasons why this development emits more CO_2. First, the service industry uses a lot of energy. Electronics, air conditioning, and other energy-intensive equipment are crucial to many services, such as banking, retail, and information technology. The sector's expansion means more energy consumption. Moreover, the expansion causes more emissions from the transportation sector as more individuals drive to and from work as the service economy expands. The situation worsens because many South Asian cities lack reliable public transport options, forcing residents to depend on their cars. The growth also triggers the emissions from the construction industry as the will be more energy-intensive buildings like offices and retail malls, with HVAC and lighting systems.

The expansion of the service industry also contributes to the rising trend of air travel, such as for business travel. Because of a shortage of ground-based transport options, air travel has become a more common option in many South Asian cities. Lastly, the growth in the service industry also results in the growth in waste-related emissions. Rising garbage collection costs are one source of CO_2 emissions related to expanding the service industry. Methane is released from landfills at a disproportionately high rate in South Asian cities due to insufficient waste management systems. Overall, the findings of the study that the service sector increases CO_2 emissions are consistent with Samarkand (2017), Alam (2015), and Butnar and Llop (2011).

6. Conclusion

The main objective of this analysis is to scrutinize the existence of the EKC hypothesis by using panel data for South Asian countries from 1972 to 2021. This study also considers the impacts of industrialization, urbanization, the service sector, and natural resources on CO_2 emission. This study employs the CSD approach to check whether study variables are interdependent. The findings of the CSD test revealed that all variables have CSD problems. This study also employs a second-generation unit root test (CIPS and CDF) to observe the stationarity, and the findings of both unit root tests showed no unit root problem in the data set. In addition, this research also used the Westerland panel cointegration approach to observe the long-run cointegration and found that variables are cointegrated in the long run.

Meanwhile, the influences of explanatory variables on dependent variables are observed using a sophisticated economic approach known as DKSE. The results of DKSE showed that GDP significantly minimizes CO_2 emissions in both the short and long runs. At the same time, GDP^2, urbanization, and the service sector increase CO_2 emissions in the SAARC region. The DK estimator also showed that industrialization and the availability of natural resources have an insignificant impact on CO_2 emissions. These results, which suggest that increasing economic growth is associated with increasing environmental pollution or escalating CO_2 levels, are inconsistent with the EKC hypothesis.

On the contrary, the EKC hypothesis predicts that ecological damage will decline when economic growth reaches a particular threshold, reflecting a predictable and systematic relationship. A novel CS-ARDL method was also utilized to confirm the findings of the DKSE estimation. The findings of CS-ARDL revealed that the EKC hypothesis does not hold in the South Asian region. Moreover, CS-ARDL estimation showed that GDP and industrialization significantly mitigate CO_2 emission, while urbanization, GDP^2, and availability of natural resources triggered CO_2 emission. Therefore, the robustness test confirms that the DKSE approach and methodology are appropriate for this research. These findings suggest the need for adequate planning for industrialization and urbanization and the improvement of productivity by using cleaner energy sources.

7. Policy implications

Our research indicates that increased economic activities have a positive effect on the environment by decreasing emissions of greenhouse gases. Hence, policymakers in the SAARC area should prioritize the production sector. Green technology-based machinery should be introduced in the manufacturing process so that output will rise to ensure environmental protection. In addition, governments should take action by offering incentives, monthly subsidies, or yearly incentives to businesses that adopt renewable technologies. Stricter regulations should also be implemented to discourage the use of industrial equipment that creates additional emissions.

Although GDP enhances the quality of the environment, GDP^2 contributes to environmental damage. This may have occurred due to low-cost, high-emitting technologies that pose a severe ecological concern. Therefore, policymakers in the SAARC region should enact clear legislation mandating the use of green technology by all industries and businesses and a mechanism of penalties for those who violate the law.

Rapid urbanization in South Asia has resulted in a significant rise in CO_2 emissions. This has had a considerable influence on the ecosystem and accelerated climate change. Policies specific to South Asia must be implemented to mitigate these negative consequences. Encouraging the use of eco-friendly transportation, including biking, carpooling, and public transportation is necessary. Fewer personal automobiles on the road will help reduce pollutants and improve urban air quality. In addition, green building regulations may help reduce carbon footprint and boost the energy efficiency of new construction. This should be accompanied by the use of renewable energy sources like solar and wind power. Lastly, recycling and composting should also be encouraged to reduce methane emissions.

The South Asian service sector has a crucial influence on rising CO_2 emissions. Promoting energy efficiency, converting to renewable energy sources, promoting low-carbon transportation choices, and enacting procurement regulations should be adopted to minimize emissions. Education and staff participation are also essential parts of lowering emissions. Businesses need to invest in carbon-reduction programs, such as reforestation or sustainable energy, to offset CO_2 emissions.

Industrialization has contributed considerably to economic growth and wealth, but at the cost of the environment. Adopting cleaner production techniques may reduce pollutants and emissions from industrial activities and enhance resource productivity. Governments could play a more significant role in monitoring and controlling industrial activities to ensure compliance with environmental standards. This might include setting emissions limits, monitoring air and water quality, and holding companies accountable for adverse environmental effects. Encouraging green business practices, such as reducing waste and emissions, using renewable materials and energy sources, and increasing resource efficiency, should also help reduce the environmental impact of industrial activities. This also includes investing in the research and development of new ecologically friendly technology.

8. Limitation and future research

While this research provides insightful findings, future research can address some limitations. First, this research may not accurately reflect the diversity of the South Asian area since it relies on data collected at the national level. The link between urbanization, industrialization, the service sector, and CO_2 emissions in various parts of South Asia could be studied using subnational or regional data. Moreover, this study focuses on urbanization, industrialization, and the expansion of the service sector affect CO_2 emissions and the economy. Future research could benefit from focusing on elements contributing to CO_2 emissions in South Asia, such as energy usage, sustainable energy growth, and government policy.

Furthermore, the correlation between economic growth and CO_2 emissions may change with time, and this analysis only covers the years 1972 to 2021. A more extended data set would allow researchers to see whether there has been a transition over time. Finally, even though this analysis concludes that the EKC theory does not pertain to South Asia, it is still feasible that other variables, such as world trade and foreign direct investment, impact the link between economic growth and CO_2 emissions. Future studies could examine how these variables affect CO_2 emissions in South Asia. In sum, while this study sheds light on the correlation between economic growth and CO_2 emissions in South Asia, future research could build on this study's limitations and investigate the elements contributing to this association.

Funding statement

This research did not receive any funding.

Consent for publication

N/A

CRediT authorship contribution statement

Mohammad Ridwan: Writing – review & editing, Methodology, Conceptualization. **Afrida Jinnurain Urbee:** Validation, Methodology, Data curation. **Liton Chandra Voumik:** Validation, Investigation, Conceptualization. **Mihir Kumar Das:** Writing – original draft, Formal analysis. **Mamunur Rashid:** Writing – original draft, Investigation. **Miguel Angel Esquivias:** Writing – review & editing, Resources.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

We can make the data available upon request.

Acknowledgement

This research was funded by Airlangga University under the Research Grant for International Collaboration 2024, grant number 182/UN3.LPPM/PT.01.03/2024.

Appendix A

List of Abbreviations.

Abbreviations	Details
CS-ARDL	Cross-Sectional Autoregressive Distributive Lag
CSD	Cross-Sectional Dependence
CO_2	Carbon Dioxide
GDP	Gross Domestic Product
GDP^2	Square of Gross Domestic Product
EKC	Environmental Kuznets Curve
DKSE	Driscoll Kraay Standard Error
QR	Quantile Regression
LCF	Load Capacity Factor
GT	Green Technology
GPR	Geopolitical Risk
REN	Renewable Energy
URBA	Urbanization
INDUS	Industrialization
SERV	Service
RES	Resource

References

Raihan, A., Farhan, S., Muhtasim, D. A., Hasan, M. A., Paul, A., & Faruk, O. (2022). The nexus between carbon emission, energy use, and health expenditure: Empirical evidence from Bangladesh. *Carbon Research, 1*(1), 30. https://doi.org/10.1007/s44246-022-00030-4

International Energy Agency. (2017). World Energy outlook. Available at: https://www.iea.org/reports/world-energy-outlook-2017. Accessed on 7 February 2023.

2020 World Bank. (2020). World Development Indicators. Available at: https://data.worldbank.org/indicator/EN.ATM.CO2E.PC. Accessed on 7 February 2023.

Rahman, M.M. (2017). Do population density, economic growth, energy use, and exports adversely affect environmental quality in populous Asian countries?. Renewable and Sustainable Energy Reviews. 77:506-14. Doi: https://doi.org/10.1016/j.rser.2017.04.041.

UN. 2017. The Emissions Gap Report 2017, a UN environment synthesis report. United Nations Environment Programme. November. Available at: https://digitallibrary.un.org/record/3894804.

Kuznets, S. (1955). International differences in capital formation and financing. In Capital formation and economic growth (pp. 19-111). Princeton University Press. Available at: https://econpapers.repec.org/bookchap/nbrnberch/1303.htm.

Kuznets, S. (1963). Quantitative aspects of the economic growth of nations: VIII. Distribution of income by size. Economic development and cultural change. 11(2-Part 2):1-80. Available at: https://www.journals.uchicago.edu/doi/abs/10.1086/450006.

Grossman GM, Krueger AB. (1991). Environmental impacts of a North American free trade agreement. Available at: https://www.nber.org/papers/w3914.

World Bank Blogs. (2022). An integrated electricity market in South Asia is key to energy security. Available at: https://blogs.worldbank.org/endpovertyinsouthasia/integrated-electricity-market-south-asia-key-energy-security. Accessed on 13 February 2023.

Ul-Haq, A., et al. (2020). Energy scenario in South Asia: Analytical assessment and policy implications. *IEEE Access 8*, 156190–156207. https://doi.org/10.1109/ACCESS.2020.3019648

Rahman, M. M., Saidi, K., & Mbarek, M. B. (2020). Economic growth in South Asia: The role of CO_2 emissions, population density and trade openness. *Heliyon, 6*(5), Article e03903.

Liu, X., & Bae, J. (2018). Urbanization and industrialization impact of CO_2 emissions in China. *Journal of Cleaner Production, 172*, 178–186. https://doi.org/10.1016/j.jclepro.2017.10.156

Li, K.e., & Lin, B. (2015). Impacts of urbanization and industrialization on energy consumption/CO_2 emissions: Does the level of development matter? *Renewable and Sustainable Energy Reviews, 52*, 1107–1122. https://doi.org/10.1016/j.rser.2015.07.185

Purwono, R., Sugiharti, L., Esquivias, M. A., Fadliyanti, L., Rahmawati, Y., & Wijimulawiani, B. S. (2024). The impact of tourism, urbanization, globalization, and renewable energy on carbon emissions: Testing the inverted N-shape environmental Kuznets curve. *Social Sciences & Humanities Open, 10*, 100917. https://doi.org/10.1016/j.ssaho.2024.100917

Rahman, M. H., & Majumder, S. C. (2020). Nexus between energy consumptions and CO_2 emissions in selected industrialized countries. *International Journal of Entrepreneurial Research, 3*(1), 13–19. https://doi.org/10.31580/ijer.v3i1.1174

Wang, L., Peng, C., Shi, W., & Zhu, M. (2020). Carbon dioxide emissions from port container distribution: Spatial characteristics and driving factors. *Transportation Research Part D: Transport and Environment, 82*, Article 102318. https://doi.org/10.1016/j.trd.2020.102318

Waqih, M. A., Ullah, et al. (2019). Rising environmental degradation and impact of foreign direct investment: An empirical evidence from SAARC region. *Journal of Environmental Management, 243*, 472–480. https://doi.org/10.1016/j.jenvman.2019.05.001

Rani, T., et al. (2022). Linking personal remittance and fossil fuels energy consumption to environmental degradation: Evidence from all SAARC countries. *Environment, Development and Sustainability*, 1–22. https://doi.org/10.1007/s10668-022-02407-2

Itoo, H. H., & Ali, N. (2023). Analyzing the causal nexus between CO_2 emissions and its determinants in India: Evidence from ARDL and EKC approach. *Management of Environmental Quality: An International Journal, 34*(1), 192–213. https://doi.org/10.1108/MEQ-01-2022-0014

Kiani, T. A., et al. (2022). Estimating the effect of technological innovations on environmental degradation: Empirical evidence from selected ASEAN and SAARC countries. *Environment, Development and Sustainability*, 1–22. https://doi.org/10.1007/s10668-022-02315-5

2020 World Bank. (2020). Leveraging Urbanization in South Asia. Available at: https://www.worldbank.org/en/region/sar/publication/urbanization-south-asia-cities. Accessed on 13 February 2023.

Rahman MM, et al. (2021). Environmental Kuznets Curve (EKC) for Bangladesh: Evidence from fully modified OLS approach. *Journal of Emerging Economies and Policy*. 6(2): 5-14. Available at: https://dergipark.org.tr/en/pub/joeep/issue/60720/888418.

Yilanci, V., & Pata, U. K. (2020). Investigating the EKC hypothesis for China: the role of economic complexity on ecological footprint. *Environmental Science and Pollution Research, 27*, 32683–32694. https://doi.org/10.1007/s11356-020-09434-4

Zhang, B., Wang, B.o., & Wang, Z. (2017). Role of renewable energy and nonrenewable energy consumption on EKC: Evidence from Pakistan. *Journal of Cleaner Production, 156*, 855–864. https://doi.org/10.1016/j.jclepro.2017.03.203

Destek, M. A., & Sinha, A. (2020). Renewable, nonrenewable energy consumption, economic growth, trade openness, and ecological footprint: Evidence from the Organization for Economic Cooperation and Development countries. *Journal of Cleaner Production, 242*, Article 118537. https://doi.org/10.1016/j.jclepro.2019.118537

Muhammad, S., et al. (2020). Effect of urbanization and international trade on CO_2 emissions across 65 belt and road initiative countries. *Energy, 196*, Article 117102. https://doi.org/10.1016/j.energy.2020.117102

Sarkodie, S. A., & Ozturk, I. (2020). Investigating the environmental Kuznets curve hypothesis in Kenya: A multivariate analysis. *Renewable and Sustainable Energy Reviews, 117*, Article 109481. https://doi.org/10.1016/j.rser.2019.109481

Suki, N. M., et al. (2020). Revisiting the environmental Kuznets curve in Malaysia: The role of globalization in a sustainable environment. *Journal of Cleaner Production, 264*, Article 121669. https://doi.org/10.1016/j.jclepro.2020.121669

Gopakumar, G., Jaiswal, R., & Parashar, M. (2022). Analysis of the existence of environmental Kuznets curve: evidence from India. *International Journal of Energy Economics and Policy, 121*(1), 177–187. https://doi.org/10.32479/ijeep.11964

Gunarathne, A. N., Kaluarachchilage, P. K., & Rajasooriya, S. M. (2020). Low-carbon consumer behavior in climate-vulnerable developing countries: A case study of Sri Lanka. *Resources, Conservation and Recycling, 154*, Article 104592. https://doi.org/10.1016/j.resconrec.2019.104592

Gupta, D., & Garg, A.. (2020). Sustainable development and carbon neutrality: Integrated assessment of transport transitions in India. *Transportation Research Part D: Transport and Environment, 85*, 102474. https://doi.org/10.1016/j.trd.2020.102474

Hamit-Haggar, M. (2012). Greenhouse gas emissions, energy consumption, and economic growth: A panel cointegration analysis from Canadian industrial sector perspective. *Energy Economics, 34*(1), 358–364. https://doi.org/10.1016/j.eneco.2011.06.005

Plassmann, F., & Khanna, N. (2006). Household income and pollution: Implications for the debate about the environmental Kuznets curve hypothesis. *The Journal of Environment & Development, 15*(1), 22–41. https://doi.org/10.1177/1070496505285466

Bibi, F., & Jamil, M. (2021). Testing environment Kuznets curve (EKC) hypothesis in different regions. *Environmental Science and Pollution Research, 28*, 13581–13594. https://doi.org/10.1007/s11356-020-11516-2

Bölük, G., & Mert, M. (2015). The renewable energy, growth and environmental Kuznets curve in Turkey: An ARDL approach. *Renewable and Sustainable Energy Reviews, 52*, 587–595. https://doi.org/10.1016/j.rser.2015.07.138

Lau, L.-S., Choong, C.-K., & Eng, Y.-K. (2014). Investigation of the environmental Kuznets curve for carbon emissions in Malaysia: Do foreign direct investment and trade matter? *Energy Policy, 68*, 490–497. https://doi.org/10.1016/j.enpol.2014.01.002

Firoj, M., et al. (2022). Pollution haven hypothesis and the environmental Kuznets curve of Bangladesh: An empirical investigation. *Asia-Pacific Journal of Regional Science, 7* (1), 197–227. https://doi.org/10.1007/s41685-022-00258-3

Mehmood, U., et al. (2022). The role of tourism and renewable energy towards EKC in South Asian countries: Fresh insights from the ARDL approach. *Cogent Social Sciences, 8*(1), Article 2073669. https://doi.org/10.1080/23311886.2022.2073669

Yousaf, A., Erum, N., & Bibi, F. (2016). Economic Growth, Foreign Direct Investment and the Environment: An Empirical Investigation for SAARC Countries.1:1-12.DOI: 10.31703/gsssr.2016(I-I).01.

Mehmood, U. (2021). Transport energy consumption and carbon emissions: The role of urbanization towards the environment in SAARC region. *Integrated Environmental Assessment and Management, 17*(6), 1286–1292. https://doi.org/10.1002/ieam.4463

Murshed, M., & Saadat, S. Y. (2018). Effects of urbanization on climate change: Evidence from Bangladesh. *Journal of Natural Sciences Research, 8*, 1–8. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3247302.

Gierałtowska, U., et al. (2022). Renewable Energy, Urbanization, and CO_2 Emissions: A Global Test. *Energies, 15*(9), 3390. https://doi.org/10.3390/en15093390

Ahmed, Z., Wang, Z., & Ali, S. (2019). Investigating the nonlinear relationship between urbanization and CO_2 emissions: An empirical analysis. *Air Quality, Atmosphere & Health, 12*, 945–953. https://doi.org/10.1007/s11869-019-00711-x

Ahmad, N., Iqbal, A., & Mahmood, H. (2013). CO_2 Emission, population and industrial growth linkages in selected South Asian countries: A cointegration analysis. *World Applied Sciences Journal, 21*(4), 615–622. https://doi.org/10.5829/idosi.wasj.2013.21.4.1989

Shahbaz, M., et al. (2016). How urbanization affects CO_2 emissions in Malaysia? The application of STIRPAT model. *Renewable and Sustainable Energy Reviews, 57*, 83–93. https://doi.org/10.1016/j.rser.2015.12.096

Siddique, H. M., & Abubakar. (2022). Industrialization, energy consumption, and environmental pollution: Evidence from South Asia. *Environmental Science and Pollution Research*, 1–9. https://doi.org/10.1007/s11356-022-22317-0

Mahmood, H., Alkhateeb, T. T. Y., & Furqan, M. (2020). Industrialization, urbanization and CO_2 emissions in Saudi Arabia: Asymmetry analysis. *Energy Reports, 6*, 1553–1560. https://doi.org/10.1016/j.egyr.2020.06.004

Raihan, A., & Tuspekova, A. (2022). Nexus between energy use, industrialization, forest area, and carbon dioxide emissions: New insights from Russia. *Journal of Environmental Science and Economics, 1*(4), 1–11. https://doi.org/10.56556/jescae.v1i4.269

Hao, Y., & Cho, H. C. (2022). Research on the relationship between urban public infrastructure, CO_2 emission, and economic growth in China. *Environment, Development and Sustainability, 24*(5), 7361–7376. https://doi.org/10.1007/s10668-021-01750-0

Hashmi, S. H., et al. (2020). Testing nonlinear nexus between service sector and CO_2 emissions in Pakistan. *Energies, 13*(3), 526. https://doi.org/10.3390/en13030526

Rehman, M. U., & Rashid, M. (2017). Energy consumption to environmental degradation, the growing appetite in SAARC nations. *Renewable Energy, 111*, 284–294. https://doi.org/10.1016/j.renene.2017.03.100

Samarkand, N. (2017). Sector value addition, technology and CO_2 emissions in Saudi Arabia. *Renewable and Sustainable Energy Reviews, 78*, 868–877. https://doi.org/10.1016/j.rser.2017.04.056

Murshed, M., et al. (2020). Value addition in the services sector and its heterogeneous impacts on CO_2 emissions: Revisiting the EKC hypothesis for the OPEC using panel spatial estimation techniques. *Environmental Science and Pollution Research, 27*, 38951–38973. https://doi.org/10.1007/s11356-020-09593-4

Akhmat, G., et al. (2014). Does energy consumption contribute to environmental pollutants? Evidence from SAARC countries. *Environmental Science and Pollution Research, 21*, 5940–5951. https://doi.org/10.1007/s11356-014-2528-1

Alam, J. (2015). Impact of agriculture, industry and service sector's value added in the GDP on CO_2 emissions of selected South Asian countries. *World Review of Business Research, 5*(2), 39–59. https://www.researchgate.net/profile/Haider-Mahmood/publication/336512934_CO_Emission_Population_and_Industrial_Growth_Linkages_2_in_Selected_South_Asian_Countries. pdf.

Driscoll, J. C., & Kraay, A. C. (1998). Consistent covariance matrix estimation with spatially dependent panel data. *Review of Economics and Statistics, 80*(4), 549–560. https://doi.org/10.1162/003465398557825

Westerlund, J. (2007). Testing for error correction in panel data. *Oxford Bulletin of Economics and Statistics, 69*(6), 709–748. https://doi.org/10.1111/j.1468-0084.2007.00477.x

Hoyos, D.e., Rafael, E., & Sarafidis, V. (2006). Testing for cross-sectional dependence in panel-data models. Available at: *The State Journal, 6*(4), 482–496 https://journals.sagepub.com/doi/pdf/10.1177/1536867X0600600403.

Rauf, A., et al. (2018). Testing EKC hypothesis with energy and sustainable development challenges: A fresh evidence from belt and road initiative economies. *Environmental Science and Pollution Research, 25*, 32066–32080. https://doi.org/10.1007/s11356-018-3052-5

Choi, I.n. (2001). Unit root tests for panel data. *Journal of International Money and Finance, 20*(2), 249–272. https://doi.org/10.1016/S0261-5606(00)00048-6

Persyn, D., & Westerlund, J. (2008). Error-correction–based cointegration tests for panel data. *The STATA Journal, 8*(2), 232–241. https://journals.sagepub.com/doi/pdf/10.1177/1536867X0800800205.

Pesaran, M. H. (2007). A simple panel unit root test in the presence of cross-section dependence. *Journal of applied econometrics, 22*(2), 265–312. https://doi.org/10.1002/jae.951

Newey, W. K., & West, K. D. (1994). Automatic lag selection in covariance matrix estimation. *The Review of Economic Studies, 61*(4), 631–653. https://doi.org/10.2307/2297912

Hasnat, G. T., Kabir, M. A., & Hossain, M. A. (2018). Major environmental issues and problems in South Asia, particularly Bangladesh. *Handbook of environmental materials management, 1-40*. https://doi.org/10.1007/978-3-319-58538-3_7-1

Hoechle, D. (2007). Robust standard errors for panel regressions with cross-sectional dependence. Available at: *The state journal, 7*(3), 281–312 https://journals.sagepub.com/doi/pdf/10.1177/1536867X0700700301.

Aye, G. C., & Edoja, P. E. (2017). Effect of economic growth on CO_2 emission in developing countries: Evidence from a dynamic panel threshold model. *Cogent Economics & Finance, 5*(1), Article 1379239. https://doi.org/10.1080/23322039.2017.1379239

Chudik, A., & Hashem Pesaran, M. (2015). Common correlated effects estimation of heterogeneous dynamic panel data models with weakly exogenous regressors. *Journal of econometrics, 188*(2), 393–420. https://doi.org/10.1016/j.jeconom.2015.03.007

Voumik, L. C., Ghosh, S., Rashid, M., Das, M. K., Esquivias, M. A., & Rojas, O. (2024). The effect of geopolitical risk and green technology on load capacity factors in BRICS. *Utilities Policy, 88*, Article 101757.

Voumik, L. C., Rahman, M., & Akter, S. (2022). Investigating the EKC hypothesis with renewable energy, nuclear energy, and R&D for EU: Fresh panel evidence. *Heliyon*, Article e12447.

Azam, M., & Khan, A. Q. (2016). Urbanization and environmental degradation: Evidence from four SAARC countries—Bangladesh, India, Pakistan, and Sri Lanka. *Environmental progress & sustainable energy, 35*(3), 823–832. https://doi.org/10.1002/ep.12282

Bakhsh, K., Rose, S., Ali, M. F., Ahmad, N., & Shahbaz, M. (2017). Economic growth, CO_2 emissions, renewable waste and FDI relation in Pakistan: New evidence from 3SLS. *Journal of environmental management, 196*, 627–632. https://doi.org/10.1016/j.jenvman.2017.03.029

Beck, N., & Katz, J. N. (1995). What to do (and not to do) with time-series cross-section data. *American Political Science Review., 89*(3), 634–647.

Ullah, S., et al. (2020). *On the asymmetric effects of premature deindustrialization on CO_2 emissions: evidence from Pakistan. Environmental Science and Pollution Research, 27*, 13692–13702. https://doi.org/10.1007/s11356-020-07931-0

Villanthenkodath, M. A., et al. (2021). Impact of economic structure on the environmental Kuznets curve (EKC) hypothesis in India. *Journal of Economic Structures, 10*(1), 1–17. https://doi.org/10.1186/s40008-021-00259-z

Minlah, M. K., & Zhang, X. (2021). Testing for the existence of the Environmental Kuznets Curve (EKC) for CO 2 emissions in Ghana: Evidence from the bootstrap rolling window Granger causality test. *Environmental Science and Pollution Research, 28*, 2119–2131. https://doi.org/10.1007/s11356-020-10600-x

Nocera, S., Maino, F., & Cavallaro, F. (2012). A heuristic method for determining CO_2 efficiency in transportation planning. *European Transport Research, 4*(2), 91–106. https://doi.org/10.1007/s12544-012-0073-x

Pata, U. K., & Aydin, M. (2020). Testing the EKC hypothesis for the top six hydropower energy-consuming countries: Evidence from Fourier Bootstrap ARDL procedure. *Journal of Cleaner Production, 264*, Article 121699. https://doi.org/10.1016/j.jclepro.2020.121699

Voumik, L. C., Rahman, M. H., & Hossain, M. S. (2022). Investigating the subsistence of Environmental Kuznets Curve in the midst of economic development, population, and energy consumption in Bangladesh: Imminent of ARDL model. *Heliyon, 8*(8), e10357.

Tenaw, D., & Beyene, A. D. (2021). Environmental sustainability and economic development in sub-Saharan Africa: A modified EKC hypothesis. *Renewable and Sustainable Energy Reviews, 143*, Article 110897. https://doi.org/10.1016/j.rser.2021.110897 S

Voumik, L. C., & Sultana, T. (2022). Impact of urbanization, industrialization, electrification, and renewable energy on the environment in BRICS: Fresh evidence from novel CS-ARDL model. *Heliyon, 8*(11), e11457.

Ali, M. U., et al. (2021). Fossil energy consumption, economic development, inward FDI impact on CO_2 emissions in Pakistan: testing EKC hypothesis through ARDL model. *International Journal of Finance & Economics, 26*(3), 3210–3221. https://doi.org/10.1002/ijfe.1958

Al-Mulali, U., et al. (2013). Exploring the relationship between urbanization, energy consumption, and CO_2 emission in MENA countries. *Renewable and Sustainable Energy Reviews, 23*, 107–112. https://doi.org/10.1016/j.rser.2013.02.041

Answer, MK, et al. (2020). Impact of urbanization, economic growth, and population size on residential carbon emissions in the SAARC countries. *Clean Technologies and Environmental Policy, 22*, 923–936. https://doi.org/10.1007/s10098-020-01833-y

Anwar, A., Younis, M., & Ullah, I. (2020). Impact of urbanization and economic growth on CO_2 emission: A case of far east Asian countries. *International Journal of Environmental Research and Public Health, 17*(7), 2531. https://doi.org/10.3390/ijerph17072531

Chauhan, M., Kumar, M., & Kumar, A. (2020 Aug). Impact of carbon stocks of Anogeissus latifolia on climate change and socioeconomic development: A case study of Garhwal Himalaya, India. *Water, Air, & Soil Pollution, 231*(8), 1–5. https://doi.org/10.1007/s11270-020-04803-8

Chen, Y., Wang, Z., & Zhong, Z. (2019). CO_2 emissions, economic growth, renewable and nonrenewable energy production and foreign trade in China. *Renewable energy, 131*, 208–216. https://doi.org/10.1016/j.renene.2018.07.047

Cheng, Z., & Xiaowen, Hu. (2022). The effects of urbanization and urban sprawl on CO_2 emissions in China. *Environment, Development and Sustainability*, 1–17. https://doi.org/10.1007/s10668-022-02123-x

Mentel, U., Wolanin, E., Eshov, M., & Salahodjaev, R. (2022). Industrialization and CO_2 Emissions in Sub-Saharan Africa: The Mitigating Role of Renewable Electricity. *Energies, 15*(3), 946. https://doi.org/10.3390/en15030946

Mignamissi, D., & Djeufack, A. (2022). Urbanization and CO_2 emissions intensity in Africa. *Journal of Environmental Planning and Management, 65*(9), 1660–1684. https://doi.org/10.1080/09640568.2021.1943329

Lee, C.-C., et al. (2022). The impact of urbanization on CO_2 emissions in China: The key role of foreign direct investment. *Emerging Markets Finance and Trade*, 1–12. https://doi.org/10.1080/1540496X.2022.2106843

Butnar, I., & Llop, M. (2011). Structural decomposition analysis and input–output subsystems: Changes in CO_2 emissions of Spanish service sectors (2000–2005). *Ecological Economics, 70*(11), 2012–2019. https://doi.org/10.1016/j.ecolecon.2011.05.017

Shahbaz, M., et al. (2014). Industrialization, electricity consumption and CO_2 emissions in Bangladesh. *Renewable and Sustainable Energy Reviews, 31*, 575–586. https://doi.org/10.1016/j.rser.2013.12.028