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ARTICLE

Influence of economic growth on environmental pollution in South Asia: a panel cointegration analysis

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Abstract

Economic growth brings fortune to a society, but it worsens the ecosystem and results in environmental pollution through carbon dioxide (CO_2) emissions. Despite extensive literature, the impact of economic growth on the environment is inconclusive, and the application of the environmental Kuznets Curve (EKC) hypothesis in the case of South Asia is very limited. This study investigated the validity of the EKC hypothesis for South Asia, examining the influence of economic growth on CO_2 emissions by incorporating industrial value added (IVA), energy consumption (ENC), and urbanization as control variables. Using annual panel data on selected South Asian economies for the period of 1971–2018, this study applied the pooled mean group and fully modified OLS estimators, and the Dumitrescu–Hurlin panel causality test to accomplish our objective. The findings revealed that economic growth, ENC, and urbanization have significant impacts on environmental pollution in South Asia. Economic growth initially adversely affects the environment, but when GDP attains a certain threshold it takes an inverse turn supported by a negative value of squared GDP, then economic growth becomes a friend of the environment. Both urbanization and ENC add to environmental pollution, and IVA is pollution-neutral. The Dumitrescu–Hurlin panel causality also reveals that economic growth, squared GDP, urbanization, and ENC contribute to CO_2 emissions. The outcomes possess implications for policymakers to increase the share of renewable energy sources in the energy mix, and emphasize rural–urban development and pollution-neutral safe production techniques to reduce environmental pollution for the region over the long run.

Keywords EKC hypothesis · CO_2 emissions · Economic growth · Energy consumption · Industrial value added · Urbanization · South Asia

JEL Classification O53 · O44 · O18 · Q53 · Q43 · R11

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1 Introduction

Economic growth measures the rise in the production of goods and services of various kinds in an economy during a year, and economists generally compute it by gross domestic product (GDP). To support the GDP to grow, an economy needs various kinds of capital, specifically natural capital, which acts as the pivot by providing raw materials of production to various sectors of an economy. When an economy grows, it brings many benefits to society. Increasing the scale of production, however, worsens the ecosystem and diminishes the natural capital, which results in an increase in carbon dioxide (CO_2) emissions. Thus, as society expands and the economy grows, developing countries face increasing environmental pollutions. It means as economic activities expand hazardous residuals flow arising from human actions enter into the environmental system. The environment has the capacity to resist pollutions produced by human actions, but once the pollution load exceeds its capacity, the environmental quality declines.

Economic growth in any developing area essentially brings reforms in the structure of the economy from agriculture to a modern industrially diverse manufacturing and service economy. When industrialization takes place, the economy develops, urban areas, as well as urban habitation expand, and environmental degradation takes place (Peng and Bao 2006). This is a common phenomenon in almost all developing economies that follow economic growth policy driven by industrialization. Thus, traditional economic theory acclaims that there exists a trade-off between environment and economic growth, because higher economic growth requires intensive and extensive use of its factors of production that invariably depletes economies' natural resources.

The process of industrialization is a pre-condition for the sustainable economic growth of any developing area, including South Asia. South Asia provides shelter to 1.87 billion people, who account for one-fourth of the world population. Despite accommodating 25% of the people of the world, South Asia remains a home of a poor level of living with little per capita income. In 2017, for instance, the regional average GDP per capita of South Asia was 1842.25 US dollars compared to 10,368.48 US dollars for East Asia and the Pacific, and 23,422.19 US dollars for Europe and Central Asia (Islam 2020). In spite, this region is growing at faster rates than many Asian countries. For example, in the year 2017, the growth rate in South Asia was 6.53% compared to 4.55% in East Asia and the Pacific, and 2.61 in Europe and Central Asia (World Bank 2020). Therefore, South Asia needs to take initiatives to accelerate environment-friendly industrial progress in the region. Accordingly, this study considers verifying the contribution of industrial value added (IVA) toward environmental quality.

Urbanization is a course of socio-economic modernization; it moves rural-based agricultural labor forces to urban-based industry and service sectors of developing countries. Owing to low productivity and subsistence living in rural areas of developing countries, rural–urban migration has been a common occurrence in South Asia that mounts pressure on urban infrastructure, basic service facilities, land, and housing, and creates much burden on the environment leading to pollution (Islam et al. 2011). Moreover, the urbanization process in South Asia is not smooth; it has been messy and hidden reflected by the widespread presence of slums and sprawl, which exerts more pressure on the environment causing environmental pollution (Ellis and Roberts 2016). Therefore, this study aims to investigate the impact of urbanization on environmental pollution using the number of the population residing in urban areas as a proxy for urbanization.

Energy is a prerequisite for higher economic growth, poverty reduction, and social development. Energy irrespective of its type is the basic input for all development activities (Islam and Ali 2011). The use of energy is indispensable for economic growth; most of the economies around the world significantly rely on conventional energy sources such as coal, oil, and natural gas to meet their energy needs. The consumption of these resources has a drastic impact on the environment causing much environmental degradation. Moreover, these sources are non-renewable, as their supply diminishes, they will be difficult to retrieve and will have a damaging effect on the environment. Hence, the provision and use of energy services are strongly connected with the economic growth and quality of the environment of the region. Therefore, investigating the contribution of energy consumption (ENC) toward CO_2 emissions seems to be a meaningful exercise.

The idea of whether economic growth causes environmental pollution, or there is any relation between the growth of an economy and the environment goes back to Simon Kuznets. Kuznets (1955) developed an economic model and demonstrated that the association between economic growth and income inequality followed an inverted U-shape. He argued that during the initial phase of economic growth, income inequalities rose, and once economic growth reached a threshold point, income inequalities started improving. Due to the occurrences of increasing environmental issues around the globe, researchers modified the famous Kuznets' curve in the 1990s to define the relationship between the level of income and the quality of the environment.

The work of Kuznets (1955) inspired Grossman and Krueger (1991) who replicated the work of Kuznets, and proposed the "Environmental Kuznets Curve" hypothesis or in short, the EKC hypothesis in the year 1991. Since then, an increasing volume of literature has appeared to suggest that there is a favorable relationship between economic growth and the quality of the environment. Therefore, economic growth is a necessary condition for a better environment. The EKC hypothesis suggests that economic growth initially results in degradation in the environment of a country. However, after the initial level of economic growth, the economy starts improving the environment, leading to a reduced level of environmental degradation. Thus, the pollution–income relationship replicates the structural change pattern in a developing country.

Table 1 An overview of CO_2 emissions and GDP in South Asia

	1980	1985	1990	1995	2000	2005	2010	2015	2018
CO_2 emissions (hundred thousand tons)									
BGD	76.38361	102.346	141.6195	211.2925	276.2718	395.0092	602.2314	810.737	670.3384
IND	3140.162	4266.738	6191.546	8115.621	10,318.53	12,225.63	17,196.91	23,377.49	20,313.25
NPL	5.42716	6.78395	7.77404	24.38555	30.69279	30.83947	50.56793	62.52235	59.67295
PAK	320.6792	471.7596	685.6557	844.8401	1064.493	1366.361	1694.667	1885.425	1917.397
LKA	34.1031	39.56693	38.68685	59.0387	102.3826	121.011	132.6354	201.135	169.3455
GDP (2010 constant billion US dollars)									
BGD	28.62692	35.27498	42.42066	52.93365	67.01347	85.86037	115.2791	156.6296	194.1462
IND	295.5898	380.1351	507.565	650.281	873.3574	1193.873	1675.615	2294.947	2822.169
NPL	4.218092	5.357076	6.697408	8.623849	10.89984	12.87756	16.00266	19.77498	22.9697
PAK	43.13406	59.8619	79.33161	99.46429	116.7539	150.1808	177.1656	215.6393	254.2151
LKA	13.67245	17.40799	20.61184	26.8067	34.2718	41.63333	56.72575	76.48584	85.51402

Source: World Bank (2020)

BGD Bangladesh, *IND* India, *NPL* Nepal, *PAK* Pakistan, *SKL* Sri Lanka

1.1 An overview of CO_2 emissions and GDP in South Asia

In South Asia, there are eight countries under the umbrella of the South Asian Association for Regional Cooperation (SAARC),[1] which was established in 1985 as a transnational and geopolitical union to promote the quality of life and economic progress in the region and to strengthen combined self-reliance. Therefore, it seems to be an important attempt to examine the economic growth and environmental pollution relation in this region. Out of eight countries of the SAARC, only five countries particularly, Bangladesh, India, Nepal, Pakistan, and Sri Lanka are selected. The other three countries are excluded due to the non-availability of required data, to investigate the influence of income growth on CO_2 emissions. To this end, an overview of CO_2 emissions and GDP in selected years for selected countries of South Asia is documented in Table 1.

Table 1 documents an overview of CO_2 emissions, and GDP for selected countries of South Asia for the last 4 decades. Among the five countries, Nepal produces the least amount of CO_2 emissions, while India generates the maximum and manifold emissions. Similarly, regarding the magnitude of the economy in terms of GDP, Nepal is relatively lagging behind the other countries under investigation. Since India is a big economy, the size of its economy is relatively far ahead of others in the region. However, as a developing area, South Asia as a whole has miles to go ahead to raise the standard of living and income of its population. Accordingly, it needs to grow in terms of income, raise its industrial value added, expand proper urbanization process, and exploit more energy to produce the desired output of goods and services; all of these activities are likely to have an impact on the environment.

[1] The eight countries of SAARC include Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, and Sri Lanka.

Therefore, this study attempts to examine the EKC hypothesis for the selected countries of South Asia, and thus, it examines the influence of GDP, IVA, urbanization, and ENC on the environment, particularly on CO_2 emissions in the region.

The investigation of the EKC hypothesis accommodates more than one explanatory variable; therefore, this study employs four different explanatory variables, which include GDP, ENC, urbanization, and IVA. The existing literature suggests that the correlation between GDP growth and the environment is inconclusive. Several studies, for example, Acaravci and Ozturk (2010), Lean and Smyth (2010), Jalil and Feridun (2011), Saboori and Sulaiman (2013), Shahbaz et al. (2014), Manuel et al. (2016), Javid and Sharif (2016), Korhan and Nigar (2018), Zhang (2018) Armeanu et al. (2018), Aruga (2019), Huangfu et al. (2020), Jiang et al (2020), Beyene and Kotosz (2020), and Udemba (2021) supported the EKC hypothesis; and while several other studies such as Harbaugh et al. (2002), Arrow et al. (1996), De Bruyn et al. (1998), Zilio and Recalde (2011), Al-Mulali et al. (2015), Zoundi (2017), Ozokcu and Ozdemir (2017), and Aruga (2019) found no support to the EKC hypothesis.

The pieces of literature cited above have examined the EKC hypothesis with different datasets in dissimilar country setups, and their results are inconclusive. This study adds industrial value added and urbanization as independent variables into the EKC model, as they may better explain the model in the context of South Asia being a developing region, and applies the pooled mean group (PMG) estimation technique, which determines the long-run and short-run coefficients simultaneously. Despite vast literature dedicated to the examination of the EKC hypothesis for many countries, its application in the case of South Asia is very limited. Therefore, this paper tries to examine the EKC hypothesis and explore the correlation between environmental pollution and income growth in South Asia incorporating IVA, urbanization, and energy consumption as control variables. The novelty of this study is the incorporation of industrial value added, urbanization, and energy consumption into the original EKC model employing the cross-sectional dependence test, second-generation panel unit root, and cointegration tests, pooled mean group (PMG), and fully modified OLS (FMOLS) estimations, and Dumitrescu–Hurlin (D–H) panel causality test. The PMG estimation takes care of heterogeneity and cross-sectional dependency issues and measures both the long-run and short-run relationships among the variables, while the D–H panel causality test is particularly suitable for the estimation of panel series with cross-sectional dependency.

The remaining parts of the paper are organized as follows. Section2 provides a review of the literature on environmental pollution and economic growth. Section 3 discusses the data and methodology, Sect. 4 reports the empirical result, and finally, Sect. 5 concludes the study.

2 Summary of the existing literature

A significant body of literature is available on the EKC hypothesis. The basis of the EKC hypothesis is the work of Kuznets (1955), who surveyed the relationship between income disparity and per capita income and concluded that when an economy boarded on its growth path, income inequality widened in the beginning, and then gradually narrowed down once the economy reached a certain stage of development. It means that income inequality reveals an inverted U-shaped association with income level. Following Kuznets (1955), Grossman and Krueger (1991) investigated the reversed U-shaped relation of income with environmental quality in a study of "potential environmental impacts of NAFTA", and named it the 'EKC' hypothesis for the first time.

The EKC hypothesis seems to be meaningful in the context of industrial development, which initially produces many emissions of pollutants; however, net emissions ultimately decline when further economic development necessarily calls for better health and environmental quality. As the economy grows, it also opts for economic liberalization, becomes keen to free trade, and foreign capital inflow especially foreign direct investment (FDI). Economic growth leading to liberalization of international trade often leads to better environmental standards (Radetzki 1992). Hence, economic growth and the environment are not hostile to each other rather the former improves the latter.

Following the influential effort of Grossman and Krueger (1991), new literature emerged in favor of the EKC hypothesis. Since then, many researchers have conducted studies to review the legitimacy of the EKC hypothesis. There is no single conclusive evidence to support the hypothesis, and empirical findings are mixed. For instance, Shafik and Bandyopadhyay (1992), Selden and Song (1993), Panayotou (1993), Acaravci and Ozturk (2010), Lean and Smyth (2010), Jalil and Feridun (2011), Saboori and Sulaiman (2013), Shahbaz et al. (2014), Manuel et al. (2016), Javid and Sharif (2016), Korhan and Nigar (2018), Zhang (2018) Armeanu et al. (2018), Aruga (2019), Huangfu et al. (2020), Jiang et al (2020), and Beyene and Kotosz (2020), supported the hypothesis.

Shafik and Bandyopadhyay (1992) estimated EKCs for ten different indicators applying three distinct functional forms, and the results were incorporated in the World Development Report 1992, which popularized the EKC hypothesis. Panayotou (1993) observed that after per capita income attained a certain level, the development process got momentum, economic growth turned to be a friend of the environment from an enemy. Therefore, economic growth seems to be an important vehicle for a better environment in developing countries, so long it stimulates policies that improve the business sector's efficiency in the use of resources. Such a policy may include structural reforms, trade liberalization, and attracting FDI inflow. Selden and Song (1993) investigated the inverted-U-shape relationship between pollution and income growth using cross-national panel data on four important air pollutants and reported an inverted-U-shape relationship between per capita emissions of all four pollutants with rising per capita income.

Ang (2007) used the cointegration approach and the VECM technique and examined the dynamic causal relationships among pollutant emissions, energy consumption, and output for France for the period 1960–2000. The study documented evidence in favor of a long-run relationship among these variables and indicated that economic growth exerted a causal impact on energy use and pollution in the long run. The results also showed a unidirectional causality from energy use to output growth in the short-run. Ang (2008) applied Johansen cointegration, the VECM analysis, and causal relationships, and investigated the relationship among output, pollutant emissions, and energy consumption in Malaysia for the period 1971–1999. The outcomes indicated that pollution and energy consumption are positively related to economic growth in the long run, and documented a causality from economic growth to energy consumption both in the short run and long run.

Acaravci and Ozturk (2010) examined the relationship among CO_2 emissions, economic growth, and energy consumption for nineteen European countries using the ARDL bounds testing model. They found energy consumption and real GDP had a long-run positive impact on CO_2 emissions, while squared GDP had a positive impact on the environmental quality, and supported the EKC hypothesis. Lean and Smyth (2010) surveyed the causal relation among CO_2 emissions, electricity consumption, and economic growth for five ASEAN countries for the period 1980–2006 using a VECM framework. They reported a positive correlation between emissions and electricity consumption, while a nonlinear relation between emissions and real output, and thus, supported the EKC hypothesis.

Jalil and Feridun (2011) studied the influence of financial development, income growth, and energy consumption on environmental degradation in China for the period 1953–2006 applying the ARDL bounds testing method. The findings reinforced the presence of an EKC for China, and concluded that CO_2 emissions were mainly contributed by income, energy use, and trade openness in the long run. Saboori and Sulaiman (2013) investigated the cointegration and causal relation between CO_2, growth of the economy, and consumption of energy in selected countries of ASEAN for the period 1971–2009. They applied the ARDL model and Granger causality test and found a nonlinear relationship between CO_2 and economic growth and thus, supported the EKC hypothesis.

Shahbaz et al. (2014) applied the ARDL bounds testing method using Tunisian data for the period 1971–2011 and examined the presence of the EKC hypothesis. They considered a structural break in their model, analyzed the causality among variables, and found a long-run relationship among the growth of the economy, energy use, trade openness, and CO_2 emissions, and supported the EKC hypothesis. Manuel et al. (2016) studied the EKC hypothesis for Brazil by examining the relationship among CO_2 emissions, economic growth, energy consumption, and electricity production for the period 1971–2011, using the ARDL approach. The study found a quadratic long-run relationship between CO_2 emissions and economic growth and confirmed the existence of the EKC hypothesis. Javid and Sharif (2016) studied the impacts of financial development, per capita income, energy use, and openness to trade on carbon emissions for Pakistan for the period 1972–2013. They applied the ARDL bounds test and confirmed the existence of the EKC hypothesis for Pakistan.

Zhang (2018) studied the linkage among CO_2 emissions, per capita real income, the share of non-fossil electricity use, and openness to trade in South Korea, and applied the ARDL cointegration approach for the period 1971–2013. The findings supported the legitimacy of the EKC hypothesis. Korhan and Nigar (2018) examined the long-run relation among CO_2 emissions, growth of income, energy consumption, and agriculture in Pakistan, and tested the EKC hypothesis for the 1971–2014 period. They considered structural breaks and applied the FMOLS method, and the findings confirmed the presence of an agriculture-induced EKC hypothesis in the case of Pakistan.

Armeanu et al. (2018) investigated the EKC hypothesis for EU-28 countries using panel data for the 1990–2014 period. They estimated the linkage among pollutant emissions, GDP per capita, industrial value added as a percentage of GDP, and primary energy consumption among others based on the pooled OLS regressions, and found evidence in favor of the EKC hypothesis. Aruga (2019) investigated the energy-environmental Kuznets curve (EECK) hypothesis for 19 Asia–Pacific countries, which was divided into the low-, middle-, and high-income groups, and validated the EEKC hypothesis for the whole Asia–Pacific region. In the case of three different income groups, the EEKC hypothesis was held only for the high-income group.

Huangfu et al. (2020) examined the impact of rapid economic growth on pollution at different municipal areas in China based on the “Stochastic Impacts by Regression on Population, Affluence, and Technology” model. They used panel data on industrial pollution and the economic performance of 290 cities from 2003 to 2016. They divided the cities into two groups based on their levels of economic development and found that a low level of economic development aggravated environmental pollution, and at a high-level environmental quality improved, and thus, found evidence in favor of the EKC hypothesis.

Jiang et al (2020) explored the relationship between economic growth and air pollution in China and Korea applying the simultaneous equation models and encompassing 286 cities in China and 228 cities and counties in South Korea for the period 2006–2016. They found an inverted U-shaped relationship between air pollution and economic growth in two countries with some visible regional differences. Beyene and Kotosz (2020) tested the EKC hypothesis for 12 East African countries using panel data and the PMG approach for the period 1990–2013 and found an inverted U-shaped relationship between per capita income and CO2 emissions. Adebayo et al. (2021) examined the relationship among CO_2 emissions, urbanization, gross capital formation, energy use, and economic growth in South Korea, utilizing time-series data for the period 1971–2018. They applied the ARDL estimation and cointegrating regression technique among others. The study reported the existence of a long-run relationship among the variables of interest and reported that CO_2 emissions triggered economic growth. They further documented unidirectional causality from CO_2 emissions and energy consumption to economic growth.

Kirikkaleli and Adebayo (2021) investigated the impact of renewable energy consumption and public–private partnership (PPP) investment in energy on consumption-based CO_2 emissions in India using quarterly data from 1990Q1 to 2015Q4 with technology innovation and economic growth as control variables. The study outcomes revealed a cointegration among consumption-based CO_2 emissions and its determinants and reported that renewable energy consumption was found useful to lower CO_2 emissions, and the PPP investments in energy made a positive contribution to lowering consumption-based CO_2 emissions in the long run. Udemba (2021) used time-series yearly data for the 1980–2018 period in UAE, examined the relationship among carbon emissions, FDI, energy use, economic growth, and population, and investigated the EKC hypothesis.

They validated the EKC hypothesis for UAE and reported a positive relationship of energy use and population with the ecological footprint, and a negative relationship between FDI and the ecological footprint.

However, the empirical evidence produced in favor of the EKC hypothesis is questioned and there are several studies, which do not support the hypothesis. Such studies, for example, include Harbaugh et al. (2002), Arrow et al. (1996), De Bruyn et al. (1998), Zilio and Recalde (2011), Al-Mulali et al. (2015), Zoundi (2017), Ozokcu and Ozdemir (2017), and Aruga (2019).

Harbaugh et al. (2002) used an updated and re-evaluated panel data set than the originally used one by Grossman and Krueger (1991), and examined the robustness of the confirmation for the presence of an inverted-U-shaped relation between income and pollution, and reported a little empirical backing for an inverted-U-shaped relationship among numerous important air pollutants and income. Arrow et al. (1996) discussed the relationship between the growth of the economy and the quality of the environment, the linkages among economic activity and the carrying capacity, and environmental resilience. They pointed out several questions and concerns and concluded that inverted-U relation might happen in some cases, but it would not establish evidence that might happen in all cases, or in time, it would prevent important and irreparable consequences of growth.

De Bruyn et al. (1998) formulated an unconventional growth model and examined three types of emissions specifically CO_2, NO_x, and SO_2 in four countries, namely The Netherlands, the United Kingdom, USA, and Western Germany. They reported that the temporal patterns of the three emissions had a positive correlation with economic growth. The study further mentioned that emissions reductions might have been achieved because of structural reforms and technological changes in the economy. Thus, they argued the inverted U-shaped relation between income and environmental pollution estimated from panel data essentially may not hold for specific individual countries over time. Zilio and Recalde (2011) used panel data for 21 countries from Latin America and Caribe for the period 1970–2007 and estimated the "energy environmental Kuznets curve". They used aggregate energy consumption to measure human-environmental pressure and GDP per capita to measure economic activity, and applied the cointegration approach, and concluded that there existed no long-run stable relationship between them, and thus, rejected the validity of energy induced EKC hypothesis.

Al-Mulali et al. (2015) investigated the presence of the EKC hypothesis in Vietnam using the ARDL method for the period 1981–2011. They analyzed the impact of GDP, imports, exports, and labor force on CO_2, and concluded that the EKC hypothesis did not exist in Vietnam as the association between GDP and environmental pollution was positive both in the short and long run. Zoundi (2017) examined the EKC hypothesis for 25 African economies in the panel cointegration framework and investigated the short- and long-run influences of renewable energy on CO_2 emissions, and reported no validation for the EKC hypothesis. Ozokcu and Ozdemir (2017) examined the EKC hypothesis and studied the relationship among CO_2 emissions, per capita GDP, and energy use for 26 OECD and 52 emerging countries for the period 1980–2010, and concluded that there existed no EKC hypothesis that implied environmental problem could not be solved by economic growth automatically.

In a study of 19 Asia–Pacific countries grouped into the low-, middle-, and high-income groups, Aruga (2019) explored the energy-environmental Kuznets curve (EECK) hypothesis, but the EEKC hypothesis did not hold for the low- and middle-income groups. Zhang (2021) investigated the EKC hypothesis for China incorporating energy consumption, trade openness, and urbanization, and used the ARDL bounds test and quantile regression technique. The study revealed an N-shaped relationship between CO_2 emissions and per capita income, a positive effect of energy consumption, and a negative effect of urbanization on CO_2 emissions in the long run.

In the literature of the EKC, environmental degradation is proxied by the pollutant CO_2 emissions as a dependent variable. Such studies include Carson (2010), Acaravci and Ozturk (2010), Zilio and Recalde (2011), Al-Mulali et al. (2015), Korhan and Nigar (2018), Zoundi (2017), Manuel et al. (2016), and Beyene and Kotosz (2020). This study uses CO_2 emissions as the dependent variable for several reasons. First, it is useful for policy debate and recommendation. For example, CO_2 represents 76.7 percent of greenhouse gas emissions (IPCC 2006) that is crucial for decision-making, economic planning, and ensuring environmental security. Besides, it is linked with vital sustainability issues including global warming and climate change.

Many studies tested the EKC hypothesis with different model specifications as a linkage of the environment with GDP including a third variable such as energy consumption, labor, population, capital, trade, globalization, FDI, and agriculture. For instance, Zhang (2018), Shahbaz et al. (2014), and Jalil and Feridun (2011) used the trade; Ozokcu and Ozdemir (2017), Saboori and Sulaiman (2013), Lean and Smyth (2010), and Aruga (2019) used energy consumption; Manuel et al. (2016) used energy consumption and electricity production; Korhan and Nigar (2018) used agriculture as an explanatory variable(s). Also, Beyene and Kotosz (2020) used FDI and globalization, Huangfu et al. (2020) used FDI, and Jiang et al. (2020) used population, and electricity consumption, population density, and employment level.

Following similar patterns, this study along with GDP and energy consumption, uses industrial value added, and urbanization as independent variables into the EKC model, as these variables together may better explain the environmental pollution in South Asia being a developing region. This is a contribution to the conventional EKC model, and it is assumed that it will further extend the understanding of the EKC hypothesis. Despite huge literature devoted to the testing of applicability of the EKC hypothesis in many countries, the application of the EKC hypothesis in the case of South Asia is very limited. Moreover, in spite of vast literature on the EKC hypothesis, the impact of economic growth on the environment is inconclusive. This study makes an effort to examine the impact of economic growth along with industrial output, urbanization, and energy consumption on CO_2 emissions in South Asia employing the PMG and FMOLS estimations, and D–H panel causality test. More specifically, this study attempts to examine the applicability of the EKC hypothesis in South Asia incorporating new explanatory variables into the conventional EKC model and investigates the impact of economic growth on environmental pollution.

Table 2 Variable specification and descriptive statistics

Var	Specification	Mean	Max	Min	S.D	Obs
LnCO_2	Stands for CO_2 emissions, measured in kilo tons and taken in natural logarithm form, as a proxy for environmental pollution	10.15	14.69	5.29	2.27	240
LnGDP	Stands for the gross domestic product as a proxy for national income in 2010 constant US dollars, taken in natural logarithm form	24.81	28.67	21.95	1.61	240
LnIVA	Stands for industrial value added, measured in 2010 constant US dollars, taken in natural logarithm form	22.75	27.29	18.21	2.01	240
LnUPN	The natural logarithm of the urban population is taken as a proxy for urbanization	16.63	19.95	13.11	1.82	240
ENC	Stands for energy consumption, measured as Kg of oil equivalent per capita	333.11	636.57	86.77	123.81	240

Source: World Bank (2020)

3 Data and methodology

A model is formulated to investigate the impact of national income, industrial value added, urbanization, and energy consumption on CO_2 emissions that is outlined in Eq. 1. The annual panel data for five South Asian economies, namely, Bangladesh, India, Nepal, Pakistan, and Sri Lanka, for the period 1971–2018 are used. The variables are specified, and descriptive statistics are exhibited in Table 2

$$\mathrm{LnCO_2} = f\left(\mathrm{LnGDP}, \mathrm{LnGDP}^2, \ \mathrm{LnIVA}, \mathrm{LnUPN}, \ \mathrm{ENC}\right). \tag{1}$$

Equation (1) is further specified in Eq. (2) as follows:

$$\mathrm{LnCO_2} = \beta_1 + \beta_2\mathrm{LnGDP} + \beta_3\mathrm{LnGDP}^2 + \beta_4\mathrm{LnIVA} + \beta_5\mathrm{LnUPN} + \beta_6\mathrm{ENC} + U_t. \tag{2}$$

The study applies the second-generation panel unit root tests as the first-generation panel unit root tests assume the cross-sections' independence, and in most cases, the cross-sections are dependent on each other. Thus, applying the first-generation panel unit root test may result in misleading outcomes. Therefore, the cross-section dependence (CD) test developed by Pesaran (2004) is applied to determine the correlation among the cross-sections, and then if cross-sections are correlated, the second-generation unit root tests, namely cross-section augmented Dickey–Fuller (CADF) panel unit root test developed by Pesaran (2007) and cross-section augmented Im, Pesaran, and Shin (CIPS) panel unit root tests developed by Pesaran et al. (2009) are used to test the stationarity of the cross-sections.

After determining the stationarity of the panel, this study applies the second-generation Westerlund (2007) cointegration tests to identify the presence of cointegration among the above variables. Westerlund (2007) cointegration test is particularly suitable under cross-sectional dependence. In the presence of cointegration among the variables, the pooled mean group (PMG) estimation developed by Pesaran et al. (1999) is conducted to determine the long-run and short-run coefficients. The PMG estimation is specifically suitable for dynamic heterogeneous panels with correlated cross-sections. It assumes the long-run coefficients to be identical but allows the short-run coefficients and error variances to vary across cross-sections. The dynamic form of the PMG estimation is illustrated in Eq. (3)

$$\mathrm{LnCO}_{2it} = \mu_i + \sum_{j=1}^{p} \vartheta_{ij}\mathrm{LnCO}_{2i,t-j} + \sum_{j=0}^{q} \theta_{ij}X_{i,t-j} + \epsilon_{i,t}, \tag{3}$$

where $i = 1, 2,\ldots, N$, represents the number of cross-sections, $t = 1, 2, 3, \ldots, T$, represents time (annual), j is the number of time lag, X_i is the vector of independent variables, and μ_1 is the fixed effect. Re-parameterizing the Eq. (3), the following equation is specified:

$$\Delta \text{LnCO}_{2it} = \mu_i + \alpha_i \text{LnCO}_{2i,t-1} + \beta_i X_{it} + \sum_{j=1}^{p-1} \vartheta_{ij}^{*} \Delta \text{LnCO}_{2i,t-j} + \sum_{j=0}^{q-1} \theta_{ij}^{*} \Delta X_{i,t-j} + \epsilon_{i,t} \quad (4)$$

where $\alpha_i = -1(-\sum_{j=1}^{p} \vartheta_{ij});\beta_i = \sum_{j=0}^{q} \theta_{ij})$.

Grouping the variables further at levels, Eq. (4) is rewritten as an error-correction form

$$\Delta \text{LnCO}_{2it} = \sum_{j=1}^{p-1} \vartheta_{ij} \Delta \text{LnCO}_{2it-j} + \sum_{j=0}^{q-1} \theta_{ij} \Delta X_{it-j} + \delta_i \left[\text{LnCO}_{2it-1} - \beta_i X_{it-1} \right] + \mu_i + \epsilon_{i,t}. \quad (5)$$

The coefficient of the error-correction term (ECT) δ_i measures the speed of adjustment of LnCO_2 to its long-run equilibrium following any change in X_{it}. The condition $\delta_i < 0$ ensures the existence of a long-run relationship. Therefore, a significant and negative value of δ_i is treated as evidence of cointegration between LnCO_2 and explanatory variables, e.g., LnGDP, ENC, LnIVA, and LnUPN. Equation (5) is estimated based on the PMG estimators.

In the presence of cointegration among the variables, the FMOLS estimators developed by Kao and Chiang (2000) are further conducted to estimate the long-run cointegration vector and check the robustness of the PMG estimators. These estimators take care of serial correlation problems and the endogeneity of regressors, which are usually present in any standard OLS long-run relationship. A fixed-effect panel regression given in Eq. (6) is considered

$$y_{it} = \alpha_i + x_{it}^{'} \beta + u_{it},\ i = 1, \dots, N;\ t = 1, \dots ..T; \quad (6)$$

where y_{it} is the dependent variable of (1,1) matrix, α_i is the individual fixed effect, $x_{it}^{'}$ is the vector of independent variables of (k,1) integrated of order 1 for all i that $x_{it} = x_{it-1} + \varphi_{it}$; β is the vector of coefficients (k,1) dimensions, and u_{it} is the stationary disturbance term.

In Eq. 6, the y_{it} and $x_{it}^{'}$ are cointegrated. The FMOLS estimator is estimated by applying the following specification given in Eq. (7)

$$\hat{\beta}_{FMOLS} = \left[\sum_{i=n}^{N} \sum_{t=n}^{T} \left(x_{it} - \bar{x}_i \right)' \right]^{-1} \left[\sum_{i=n}^{N} \left\{ \sum_{t=1}^{T} \left(\left(x_{it} - \bar{x}_i \right) \right) \right\} \hat{y}_{it}^{+} + T \hat{\omega}_{\varphi u}^{+} \right], \quad (7)$$

where the term $\hat{\omega}_{\varphi u}^{+}$ corrects the serial correlation and $\hat{y}_{it}^{+}$ is the transformed form of the variable of y_{it} to correct the endogeneity problem.

Finally, the Dumitrescu and Hurlin (2012) panel causality test is employed to define the direction of causality among the variables. This test is specifically suitable for the estimation of panel series with cross-section dependency. It adopts all

Table 3 Cross-sectional dependence (CD) test result

Variable	CD test	*p* value	Corr	Abs (corr)
$LnCO_2$	20.96	0.000***	0.957	0.957
LnGDP	21.72	0.000***	0.992	0.992
LnUPN	21.72	0.000***	0.991	0.991
LnIVA	21.44	0.000***	0.978	0.978
ENC	20.21	0.000***	0.922	0.922

CD ~ *N* (0,1)

***Significance at the 1% level

Table 4 Panel unit root test results

Variable	CADF		CIPS	
	level	First difference	Level	First difference
$LnCO_2$	− 1.756	− 5.178***	− 3.389***	–
LnGDP	− 1.329	− 4.4282***	− 1.954	− 5.699***
LnIVA	− 2.957***	–	− 2.654***	–
LnUPN	− 1.946	− 2.163	− 2.505**	–
ENC	− 1.985	− 5.976***	− 2.031	− 6.133***

***,**Significance at 1 and 5% levels, respectively

coefficients to differ across different cross-sections. The D-H model is outlined in Eq. (8)

$$Y_{it} = \alpha_i + \sum_{i=1}^{k} \gamma_i Y_{i,t-k} + \sum_{i=1}^{k} \delta_i X_{i,t-k} + \epsilon_{i,t}, \tag{8}$$

where constant α_i,γ_i, and δ_i represent, respectively, the constant term, lag parameter, and coefficient slope. The null and alternative hypotheses are stated as follows:

$$H_0 : \delta_i = 0, H_1 : \begin{cases} \delta_i = 0, \forall_i = 1,2,\ldots N \\ \delta_i \neq 0, \forall_i = N_1+1, N_1+2,\ldots N \end{cases}.$$

The null hypothesis indicates the existence of no homogenous Granger causality for all cross-sectional units, while the alternative hypothesis shows that there is at least one causal relationship in the panel data.

Table 5 Westerlund cointegration test results

Statistic	Value	*Z* value	*P* value
Gt	− 1.789	0.413	0.660
Ga	− 10.617	− 01.432	0.041**
Pt	− 9.376	− 4.547	0.000***
Pa	− 12.951	− 2.091	0.018**

***,**Significance at the 1 and 5% levels, respectively

4 Results and discussion

4.1 Cross-sectional dependence (CD) test

The results of the Pesaran (2004) CD test are summarized in Table 3 and show that all the cross-sections are correlated across panel groups at the 1% significance level.

4.2 Panel unit root test results

Since there exists a cross-sectional dependency, the CADF panel unit root test results based on Pesaran (2007) and CIPS panel unit root test results based on Pesaran et al. (2009) are reported in Table 4.

The panel unit root test results presented in Table 4 exhibit that the variables are integrated at different orders at 1% and 5% levels of significance, and they are I(0) and I(1).

4.3 Cointegration test results

4.3.1 Second generation cointegration test results

The second-generation Westerlund (2007) panel cointegration tests is applied under the constant assumption, with lags(0 1) leads (01) lrwindow(2). The results are recorded in Table 5. It shows that the null hypothesis of no cointegration is rejected as the Ga, Pt, and Pa statistics are significant at the 5 and 1% levels of significance. Therefore, the variables have a long-run cointegrating relationship.

4.3.2 PMG estimators

Based on the unit root tests and the cointegration test results, the PMG estimation technique is applied to determine the long-run and short-run relationships. The model is specified as ARDL (2, 1, 1, 1, 1) based on the automatic lag selection with four lags for the dependent variable and 1 lag for dynamic regressors, following the AIC and the results are reported in Table 6.

The estimated PMG model results presented in Table 6 provide both the long-run and short-run relationships and document the impact of the independent variables on CO_2 emissions. The coefficients of LnGDP, ENC, and LnUPN are positive

Table 6 PMG estimation results

Variable	Coefficient	Std. error	*t*-Statistic	Probability
Long-run equation				
LnGDP	12.0209	1.1678	10.294	0.0000***
$LnGDP^2$	− 0.2136	0.0217	− 9.8455	0.0000***
LnIVA	− 0.05289	0.0427	− 1.2392	0.2167
LnUPN	0.2426	0.1141	2.1252	0.0348**
ENC	0.0029	0.0005	5.6048	0.0000***
Short-run equation				
ECT	− 0.4331	0.1698	− 2.5505	0.0115**
D(LnGDP)	48.9448	21.495	2.2770	0.0238**
D($LnGDP^2$)	− 1.0465	0.4603	− 2.2734	0.0241**
D(LnIVA)	− 0.0528	0.0652	− 0.8092	0.4194
D(LnUPN)	0.2804	2.3063	0.12158	0.9034
D(ENC)	0.0012	0.0010	1.2373	0.2174
C	− 69.186	27.1354	− 2.5497	0.0115**

**, ***Significance at the 5 and 1% levels, respectively

and significant, meaning that they have a long-run affirmative influence on CO_2 emissions.

The coefficient of LnGDP is positive and significant at the 1% significance level. When GDP grows, an increasing volume of goods and services are produced using various kinds of raw materials, which discharges CO_2 into the atmosphere. Therefore, GDP has a positive impact on CO_2 emissions. Moreover, the structure of South Asia's economies has been transforming from agriculture to modern industry and service-based economy since the 1980s. Consequently, the pace of urbanization and urban habitation has expanded leading to environmental pollution. For example, in 1986, the share of broad agriculture in Bangladesh, India, Pakistan, and Sri Lanka was 32.37, 27.47, 25.03, and 27.46%, respectively, which declined to 17.07, 15.41, 22.86, and 7.92%, and consequently, that of manufacturing, industry, and service sectors was increased significantly (World Bank 2020).

However, the coefficient of squared LnGDP is negative and significant at the 1% level of significance. It implies that as these economies keep on growing, the standard of living increases, health facilities and services increase, measures for safety, and quality control become mandatory in the economic sphere. These measures help to reduce environmental pollution. This phenomenon is validated by the negative value and significant coefficient of the squared GDP, meaning that the squared GDP causes CO_2 emissions to decline. That is to say, as GDP keeps on growing, after a certain level it takes inverse shape that supports the EKC hypothesis in the selected countries of South Asia. These findings are similar to the findings of earlier studies such as Shafik and Bandyopadhyay (1992), Selden and Song (1993), Panayotou (1993), Manuel et al. (2016), Korhan and Nigar (2018), Armeanu et al. (2018), Beyene and Kotosz (2020), and Udemba (2021) and support the EKC hypothesis.

The coefficient of LnIVA is insignificant, meaning that any increase in industrial output is environmental pollution-neutral. The industry is one of the major providers of goods and services to the economy and contributors to economic growth. It uses various types of inputs, employs production techniques, and converts them into finished goods and services. It is conceivable that industrial output is likely to discharge pollutants and cause the environment negatively, but the findings reveal an environmentally-friendly role of industrial value addition. The finding provides some relief for the policymakers that in industrial production, they may continue with the existing production methods, which are friendly to the environment.

The coefficient on LnUPN is positive and significant at the 5% level of significance, indicating that urbanization exerts a positive impact on environmental pollution in South Asia. Evidence shows that South Asia has witnessed a significant surge in urbanization, and the percentage of the population living in the urban areas has grown significantly over the years. For example, urban population in Bangladesh, India, Nepal, Pakistan, and Sri Lanka in 1971 was, respectively, 7.90, 19.99, 4.01, 25.08, and 17.70% which increased to 36.63, 34.03, 19.74, 36.67, and 18.48% in 2018 (World Bank 2020). As South Asia hosts 25% of the world population with a low level of income amidst huge income inequality (Islam 2020), rural–urban migration has been a common phenomenon in this region. Generally, rural people trapped in poverty caused by man-made and natural calamities migrate to cities in the hope of better employment, and opportunities create urban problems such as slums causing environmental degradation (Islam et al. 2011). This is particularly true for South Asia, because the process of urbanization has been messy and hidden reflected by the widespread presence of slums and sprawl in this region. The pressure of urban inhabitants on infrastructure, basic service facilities, land, housing, etc., resulting from messy and hidden urbanization creates environmental problems (Ellis and Roberts 2016). The finding has implications for the policymakers to focus on rural development and proper urban planning in the transformation of their economies, so that environmental pollution is the minimum.

The coefficient of ENC is also positive and statistically significant at the 1% level. Energy consumption in selected countries produces enough environmental pollutions as they largely rely on conventional energy sources, and less on renewable energy sources to carry out economic activities. For example, the shares of renewable energy use in Bangladesh, India, Pakistan, and Sri Lanka in 2015 were only 34.75, 36.02, 46.48, and 52.88% (World Bank 2020). The use of energy has become indispensable, as energy is an input of production to achieve sustainable economic growth; the higher the use of energy, the greater is the richness of a country that enables a high standard of living in stimulating economic growth, and there is a nexus between energy use and economic growth which is observed in the literature (Akarca and Long 1980; Wolde-Rufael 2005; Marques et al. 2016). Therefore, curtailing energy consumption will lead to a decline in GDP and a deceleration in economic growth. Accordingly, a mitigating role on the part of governments and policymakers is warranted that leads to the managerial implications for the policymakers and the governments of South Asia to diversify their country-energy portfolios toward more renewable energy sources, and increase the share of renewable energies as they cannot reduce energy consumption that will keep the pollutant emissions to a minimum.

Table 7 FMOLS estimation results

Variable	Coefficient	Std. Error	*t*-Statistic	Probability
LnGDP	3.1465	0.4781	6.5807	0.0000***
$LnGDP^2$	− 0.0532	0.0091	− 5.8328	0.0000***
LnIVA	− 0.0833	0.0731	− 1.1391	0.2559
LnUPN	0.7999	0.0783	10.2182	0.0000***
ENC	0.0028	0.0008	3.5386	0.0005***

***Significance at the 1% level

The short-run dynamics reveal that the coefficient of LnGDP is positive, while the coefficient of $LnGDP^2$ is negative, and both are significant. Thus, economic growth causes environmental pollution positively, while squared GDP causes it negatively in the same fashion as they do in the long run. Neither energy consumption nor industrial value added nor urbanization affects environmental pollution in the short run. The negative and significant value of the coefficient of ECT validates the cointegrating relationship among the variables. It also exhibits that the speed of adjustment to a long-run equilibrium from short-run variations that will take place at the rate of 43.13% per year.

4.4 The FMOLS estimation results

The robustness check is done using the FMOLS estimation results, which are based on the constant trend specification and pooled estimation method, and reported in Table 7. The findings are very similar to those of PMG estimation. The coefficients of LnGDP, ENC, and LnUPN are positive and significant, whereas the coefficient of square LnGDP is negative. Thus, like the PMG estimation, the FMOLS estimation also documents that LnGDP, LnUPN, and ENC have long-run positive and squared GDP have long-run negative influences of CO_2 emissions. Thus, energy consumption and urbanization add to environmental pollution, while economic growth initially deteriorates the environmental quality but eventually takes care of it. Industrial value added remains pollution-neutral.

The findings suggest that to mitigate environmental pollution, energy consumption should be curtailed, which is not possible, because restraining energy consumption will result in the deceleration of economic growth. Hence, South Asia should focus on the composition of the energy mix and diversify its energy portfolio from conventional energy sources toward renewable sources such as solar, hydro, and air. The region under the umbrella of the SAARC even may go for new joint renewable energy generation projects, as well. Similarly, the region may continue its industrial production using environment-friendly production technology. Moreover, proper planning and initiatives need to be taken for rural–urban development in the socio-economic transformation of the economies. Such collective actions and efforts may fulfill the goals of the SAARC to promote the standard of living and enhance economic growth and strengthen the collective self-reliance and reduce environmental pollution in the region in the long run.

Table 8 Pairwise Dumitrescu–Hurlin panel causality test results, lags: 1

Null hypothesis:	W-Stat	Zbar-Stat	Prob	Decision
LnGDP does not cause $LnCO_2$	23.3692	32.4929	0.0000***	LnGDP ↔ $LnCO_2$,bidirectional
$LnCO_2$ does not cause LnGDP	10.4263	13.6523	0.0000***	
$LnGDP^2$ does not cause $LnCO_2$	19.9509	27.5169	0.0000***	$LnGDP^2$ ↔ $LnCO_2$, bidirectional
$LnCO_2$ does not cause $LnGDP^2$	9.59087	12.4361	0.0000***	
ENC does not cause $LnCO_2$	5.4725	6.4412	0.000***	ENC ↔ $LnCO_2$, bidirectional
$LnCO_2$ does not cause ENC	5.2433	6.1075	0.000***	
LnUPN does not cause $LnCO_2$	34.3651	48.4991	0.0000***	LnUPN → $LnCO_2$, unidirectional
LnCO2 does not cause LnUPN	1.6927	0.9389	0.3477	
ENC does not cause LnUPN	14.2045	19.1521	0.0000***	ENC ↔ LnUPN, bidirectional
LnUPN does not cause ENC	4.2513	4.6635	0.000***	
LnUPN does not cause LnGDP	2.8877	2.6785	0.0074***	LnUPN ↔ LnGDP, bidirectional
LnGDP does not cause LnUPN	11.3198	14.9529	0.0000***	
LnUPN does not cause LnIVA	2.1939	1.6686	0.0952*	LnUPN ↔ LnIVA, bidirectional
LnIVA does not cause LnUPN	8.6730	11.1000	0.0000***	
LnIVA does not cause LnGDP	2.7562	2.4872	0.0129**	LnIVA ↔ LnGDP, bidirectional
LnGDP does not cause LnIVA	3.5881	3.6981	0.0002***	
ENC does not cause LnGDP	0.9111	-0.1987	0.8425	LnGDP → ENC, unidirectional
LnGDP does not cause ENC	6.7649	8.3224	0.0000***	
ENC does not cause LnIVA	2.0504	1.4597	0.1444	LnIVA → ENC, unidirectional
LnIVA does not cause ENC	4.5512	5.0999	0.000***	
LnIVA does not cause $LnCO_2$	18.7071	25.7063	0.0000**	LnIVA → $LnCO_2$, unidirectional
$LnCO_2$ does not cause LnIVA	1.8521	1.1710	0.2416	

***, **, *Significance at the 1, 5, and 10% levels, respectively

4.5 D–H panel causality test results

The D–H (2012) panel causality test results documented in Table 8 reveal seven bidirectional and four unidirectional causalities. The first bidirectional causality is reported from economic growth to environmental pollution (LnGDP ↔ $LnCO_2$), which indicates that economic growth positively causes the latter. The second bidirectional causality ($LnGDP^2$ ↔ $LnCO_2$), reveals that squared GDP causes CO_2 emissions negatively, meaning that it improves environmental quality. These two bidirectional causalities together authenticate the EKC hypothesis for South Asia and show the importance of economic growth in achieving sustainable economic development in the region. The third bidirectional causality from energy consumption to environmental pollution (ENC ↔ $LnCO_2$) exhibits a feedback relationship between them, implying that an increase in energy consumption enhances environmental pollution and vice versa. This calls for a mitigating measure on the part of the policymakers and governments to control the damaging impact of energy use on the environment.

The first unidirectional causality (LnUPN → $LnCO_2$) indicates that urbanization causes environmental pollution. The above four causalities authenticate the findings of the PMG and the FMOLS estimators. These prove the robustness of the findings by the regression analyses.

The fourth bidirectional causality exists between energy consumption and urbanization (ENC ↔ LnUPN). An increase in urban population leads to enhanced energy use and vice versa. The fifth bidirectional causality persists between urbanization and economic growth (LnUPN ↔ LnGDP). A rise in urbanization causes economic growth and vice versa. The sixth bidirectional causality (LnUPN ↔ LnIVA) occurs between urbanization and industrial value added. An increase in urban population raises industrial output and vice versa. The seventh bidirectional causality prevails between LnIVA ↔ LnGDP, industrial output causes economic growth, and vice versa.

The second unidirectional causality from LnGDP to ENC highlights a positive role of economic growth on energy consumption, indicating as economic growth takes place energy demand and its use gets momentum. The third unidirectional causality runs from LnIVA → ENC, an enhanced industrial output causes augmented energy use, which is obvious. The fourth and last unidirectional causality remains from LnIVA → LnCO_2; an increase in industrial output directly or indirectly causes environmental pollution.

5 Conclusion and policy implications

The study has attempted to examine the effect of national income, industrial value added, urbanization, and energy consumption on CO_2 emissions in South Asia. The Westerlund cointegration test has provided evidence in favor of a long-run relationship among the variables under consideration, where national income, urbanization, and energy consumption have significant influences on CO_2 emissions.

Both the PMG and FMOLS estimators have confirmed that while GDP growth adversely affects the environment; squared GDP takes care of the environment. As economic growth takes place, GDP grows and it causes CO_2 emissions to grow leading to environmental pollution. However, as GDP grows faster, and the economy reaches a threshold level, it takes an inverse turn because of the negative coefficient of the squared GDP, and economic growth turns to be a friend of the environment. Thus, an environmental Kuznets curve exists for South Asia.

From the D–H (2012) panel causality test, it appears that economic growth, squared GDP, urbanization, and energy consumption cause CO_2 emissions, and supports the findings of the PMG and FMOLS estimates. Besides, there are several bidirectional and unidirectional causalities running among the variables of interest.

Energy consumption has contributory impacts on environmental pollution, meaning that an increase in energy use damages environmental quality. Nonetheless, it is not possible to reduce energy consumption, as curtailing energy use will drastically affect the socio-economic growth and development of the region. Since the countries are using more non-renewable energies and less renewable ones, the conceivable and possible way of reducing the harmful impact of energy consumption on the environment is to enhance the use of renewable energies.

The growth in industrial output greatly shapes the nature and extent of national income. The larger is the volume of industrial output, the higher is the national income and the more is the standard of living. Industrial value added remains pollution-neutral, which is comfortable for the policymakers of the region. Therefore, South Asia should continue using efficient and safer production techniques to continue pollution-neutral industrial value addition.

Generally, urbanization tends to greater density, rise in productivity. However, the urbanization in South Asia has been unusual, messy, and hidden reflected by the widespread presence of slums and sprawl. Urban sprawl has given rise to hidden urbanization especially on the peripheries of the major cities, which are not captured in the official statistics. The pressure of urban inhabitants on infrastructure, and urban service providers resulting from messy urbanization has a damaging impact on the environment.

Based on the foregoing analysis, the policymakers of South Asia should focus on the diversification of their energy portfolios. They must focus on renewable energies, enhance the generation and use of renewable energy, and reduce the use of conventional ones. Moreover, they need to continue and emphasize pollution-neutral production techniques to maintain environment-friendly industrial value addition. The policymakers must find ways for rural–urban development through proper planning and find a solution for the messy urbanization process to minimize environmental pollutions. Above all, economic growth must be ensured through the generation and use of appropriate energy, production of industrial value added, and proper rural–urban development and urbanization. These measures will realize the goals of the SAARC to enhance the standard of living and expand economic growth and strengthen collective self-reliance and reduce environmental pollutions in the region in the long run.

The study has considered only five countries of South Asia leaving the other three due to the non-availability of sufficient data, which is a limitation. A similar study may be conducted in the future incorporating more countries, which will make the study more comprehensive.

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Declarations

Conflict of interest There are no conflicts of interest/competing interests.

References

Acaravci A, Ozturk I (2010) On the relationship between energy consumption, CO_2 emissions, and economic growth in Europe. Energy 35:5412–5420

Adebayo TS, Awosusi AA, Kirikkalel D, Akinsola GD, Mwamba MN (2021) Can CO_2 emissions and energy consumption determine the economic performance of South Korea? A time-series analysis. Environ Sci Pollut Res. https://doi.org/10.1007/s11356-021-13498-1

Akarca AT, Long TV (1980) On the relationship between energy and GNP: a reexamination. J Energy Dev 5:326–331

Al-Mulali U, Saboori B, Ozturk I (2015) Investigating the environmental Kuznets curve hypothesis in Vietnam. Energy Policy 76:123–131

Ang JB (2007) CO_2 emissions, energy consumption, and output in France. Energy Policy 35(10):4772–4778

Ang JB (2008) Economic development, pollutant emissions, and energy consumption in Malaysia. J Policy Model 30(2):271–278

Armeanu D, Vintilă G, Andrei JV, Gherghina SC, Drăgoi MC, Teodor C (2018) Exploring the link between environmental pollution and economic growth in EU-28 countries: Is there an environmental Kuznets curve? PLoS ONE. https://doi.org/10.1371/journal.pone.0195708

Arrow K, Bolin B, Costanza R, Dasgupta P, Folke C, Holling CS, Jansson B, Levin S, Mäler K, Perrings C, Pimentel D (1996) Economic growth, carrying capacity, and the environment. Environ Dev Econ 1:104–110

Aruga K (2019) Investigating the energy-environmental Kuznets curve hypothesis for the Asia-Pacific region. Sustainability 11:2395. https://doi.org/10.3390/su11082395

Beyene SD, Kotosz B (2020) Testing the environmental Kuznets curve hypothesis: an empirical study for East African countries. Int J Environ Stud 77(4):636–654

Carson RT (2010) The environmental Kuznets curve: seeking empirical regularity and theoretical structure. Rev Environ Econ Policy 4(1):3–23

De Bruyn SM, van den Berghm J, Opschoor JB (1998) Economic growth and emissions: reconsidering the empirical basis of environmental Kuznets curves. Ecol Econ 25(2):161–175

Dumitrescu EI, Hurlin C (2012) Testing for Granger non-causality in heterogeneous panels. Econ Model 29(4):1450–1460

Ellis P, Roberts M (2016) Leveraging urbanization in South Asia: managing spatial transformation for prosperity and livability. World Bank, Washington, DC

Grossman GM, Krueger AB (1991) Environmental impacts of a North American free trade agreement. Working Paper 3914, National Bureau of Economic, Cambridge

Harbaugh WT, Levison A, Wilson DM (2002) Reexamining the empirical evidence for an environmental Kuznets curve. Rev Econ Stat 84(3):541–551

Huangfu Z, Hu H, Xie N, Zhu Y-Q, Hao Chen H, Wang Y (2020) The heterogeneous influence of economic growth on environmental pollution: evidence from municipal data of China. Pet Sci 17:1180–1193

Intergovernmental Panel on Climate Change (IPCC) (2006) 2006 IPCC guidelines for national greenhouse gas inventories. Retrieved from: https://www.ipcc-nggip.iges.or.jp./public/2006gl/index.html

Islam MS (2020) Human capital and per capita income linkage in South Asia: a heterogeneous dynamic panel analysis. J Knowl Econ 11(4):1614–1629

Islam MS, Ali BMA (2011) Energy consumption and economic development in Bangladesh: an empirical study. Asia Pac J Soc Sci Special issue (2):44–58

Islam MS, Rashid HA, Howlader A, Ahmed MF (2011) Rural–urban migration: a quest for economic development and poverty reduction. J Econ Policy Res 6(2):119–136

Jalil A, Feridun M (2011) The impact of growth, energy, and financial development on the environment in China: a cointegration analysis. Energy Econ 33:284–291

Javid M, Sharif F (2016) Environmental Kuznets curve and financial development in Pakistan. Renew Sustain Energy Rev 54(54):406–414

Jiang M, Kim E, Woo Y (2020) The relationship between economic growth and air pollution—a regional comparison between China and South Korea. Int J Environ Res Public Health 17:2761. https://doi.org/10.3390/ijerph17082761

Kao C, Chiang MH (2000) On the estimation and inference of a cointegrated regression in panel data. In: Baltagi B (ed) Nonstationary panels, panel cointegration, and dynamic panels, advances in econometrics, 15. JAI Press, Amsterdam, pp 161–178

Kirikkaleli D, Adebayo TS (2021) Do public-private partnerships in energy and renewable energy consumption matter for consumption-based carbon dioxide emissions in India? Environ Sci Pollut Res 28:30139–30152

Korhan KG, Nigar T (2018) Testing the agriculture-induced EKC hypothesis: the case of Pakistan. Environ Sci Pollut Res. https://doi.org/10.1007/s11356-018-2330-6
Kuznets S (1955) Economic growth and income inequality. Am Econ Rev 49:l–28
Lean HH, Smyth R (2010) CO_2 emissions, electricity consumption, and output in ASEAN. Appl Energy 87(6):1858–1864
Manuel AZM, Ivanna VB, Joseph AB, María MJ (2016) Relationship between economic growth and environmental degradation: is there an environmental evidence of kuznets curve for Brazil? Int J Energy Econ Policy 6(2):208–216
Marques LM, Fuinhas JA, Marques AC (2016) On the global energy consumption and economic growth nexus: a long time span analysis. Int Energy J 15(4):143–150
Ozokcu S, Ozdemir O (2017) Economic growth, energy, and environmental Kuznets curve. Renew Sustain Energy Rev 72:639–647
Panayotou T (1993) Empirical test and policy analysis of environmental degradation at different stages of economic Development (Working Paper, p 238). Technology and employment program, International Labor Office, Geneva
Peng S, Bao Q (2006) Economic growth and environmental pollution: an empirical test for the environmental Kuznets Curve hypothesis in China. Res Financ Econ Issues 8:3–17
Pesaran MH (2004) General diagnostic tests for cross-section dependence in panels. IZA Discussion Paper No. 1240
Pesaran MH (2007) A simple panel unit root test in the presence of cross-section dependence. J Appl Econom 22(2):265–312
Pesaran MH, Shin Y, Smith RP (1999) Pooled mean group estimation of dynamic heterogeneous panels. J Am Stat Assoc 94(446):621–634
Pesaran MH, Smith V, Yamagata T (2009) Panel unit root tests in the presence of a multifactor error structure. Cambridge University, unpublished working paper, September
Radetzki M (1992) Economic growth and environment. In: Low P (ed) International trade and the environment, World Bank DP-159 (World Bank, Washington, DC) pp 121–136
Saboori B, Sulaiman J (2013) CO_2 emissions, energy consumption, and economic growth in the Association of Southeast Asian Nations (ASEAN) countries: a cointegration approach. Energy 55:813–822
Selden TM, Song D (1993) Environmental quality and development: is there a Kuznets curve for air pollution emissions? J Environ Econ Manag 27:147–162
Shafik N, Bandyopadhyay S (1992) Economic growth and environmental quality. Working paper, World Development Report
Shahbaz M, Khraief N, Uddin GS, Ozturk I (2014) Environmental Kuznets curve in an open economy: a bounds testing and causality analysis for Tunisia. Renew Sustain Energy Rev 34:325–336
Udemba EN (2021) Nexus of ecological footprint and foreign direct investment pattern in carbon neutrality: new insight for the United Arab Emirates (UAE). Environ Sci Pollut Res. https://doi.org/10.1007/s11356-021-12678-3
Westerlund J (2007) Testing for error correction in panel data. Oxford Bull Econ Stat 69(6):709–748
Wolde-Rufael Y (2005) Energy demand and economic growth: the African experience. J Policy Model 27(8):891–903
World Bank (2020) World development indicators. http://databank.worldbank.org
Zhang S (2018) Is trade openness good for the environment in South Korea? The role of non-fossil electricity consumption. Environ Sci Pollut Res 25:1–13
Zhang J (2021) Environmental Kuznets curve hypothesis on CO_2 emissions: evidence for China. J Risk Financ Manag 14:93. https://doi.org/10.3390/jrfm14030093
Zilio M, Recalde M (2011) GDP and environment pressure: the role of energy in Latin America and the Caribbean. Energy Policy 39(12):7941–7949
Zoundi Z (2017) CO_2 emissions, renewable energy, and the environmental Kuznets curve, a panel cointegration approach. Renew Sustain Energy Rev 72:1067–1075