The non-linear relationship between economic development and air pollution: evidence from panel data analysis

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Abstract

Purpose – This article aims to analyze the connection between economic growth and air pollution within Asian countries. The report aims to take further steps to examine a non-linear relationship between economic expansion and environmental degradation, with a particular focus on a turning point. The results could help policymakers in Asian countries to improve their economies sustainably.

Design/methodology/approach – This study collects data from 27 West and South Asian nations from 2000 to 2020. The authors implement the Driscoll–Kraay Standard Estimator method to deal with cross-sectional dependence, heteroskedasticity, and autocorrelation problems.

Findings – Our results show that when gross domestic product increases by 1%, emissions decrease by 3.254%. However, when countries reach higher levels of economic development and a certain income level reaches 4,126.25 USD, economic growth increases CO2 emissions by 0.45%, pointing to a U-shaped relationship between economic growth and air pollution. Although these results are consistent with the green growth theory, they do not support the pollution haven or the environmental Kuznets curve (EKC) hypothesis.

Practical implications – Our research provides policymakers and economic operators with rich empirical evidence for new strategies to develop local economies sustainably without encountering environmental problems. Firstly, policymakers could rely on the findings of this study to identify the economic development threshold that helps reduce environmental degradation. In addition, greener business practices, public awareness toward climate change and circular economies are suitable suggestions for policymakers to develop sustainable growth in Asian nations.

Originality/value – This study comprehensively analyzes the relationship between economic growth and CO2 emissions in West and South Asian countries, integrating economic, environmental and social perspectives. It challenges the EKC hypothesis by identifying a U-shaped relationship, where early growth reduces emissions, but industrial expansion beyond a certain income threshold increases them. The study uses the Driscoll–Kraay standard error method to ensure robust findings by addressing statistical issues. Examining diverse economic structures and environmental conditions advances research and offers valuable insights for sustainable development policies.

Keywords Carbon dioxide emission, Economic development, West Asia, South Asia, Kuznets curve, Driscoll–Kraay standard estimator

Paper type Research paper

1. Introduction

Population growth and economic expansion have been highlighted by recent studies as important in increasing pollution emissions, including CO2 emissions. Researchers and

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political leaders understand that reducing emissions and adapting to climate change is a moral issue and an important part of ensuring sustainable development. For instance, Mikayilov *et al*. (2018) and Panayotou (2016) report that the influence of economic growth on environmental degradation needs to be analyzed in detail and described from many different angles. The present study provides a more comprehensive and multidimensional view of how economic growth can affect CO2 emission levels from economic, environmental, and social perspectives. Therefore, it raises important questions about the environmentally destructive potential of economic growth and provides greater insight into the association between the process of economics and climate change.

This study explores the relationship between GDP and CO2 discharge in several West and South Asian countries, motivated by the following reasons. Firstly, current research has explored how the growth in the economy affects CO2 emissions with various outcomes. For example, Zhang *et al*. (2019) discovered that economic development has the most significant positive impact on emissions from major economic sectors. Hang *et al.* (2019) delved into the complex relationship between GDP and pollution emissions. They emphasize that, as economic activities increase, this often goes hand in hand with increased energy consumption and pollution emissions. Pollution poses a threat to the environment and can hinder economic progress.

In contrast, Cantore and Padilla (2010) and Tran *et al*. (2023) identified a negative nexus between economic growth and environmental pollution. This study suggests that income increases often encourage efficient use of energy resources and cleaner production practices. Overall, the study emphasizes the inverse relationship between economic development and CO2 emission reduction, creating the potential for achieving equilibrium between economic development and environmental protection. Due to changes in consumption patterns, higher-income individuals favor less carbon-intensive goods and services. In addition, economic shifts toward services, increased environmental awareness, and policies targeting income inequality contribute to the observed reduction in emissions as income increases. Furthermore, the trend of investing in green technology and renewable energy is being strongly promoted by both the public and private sectors, especially in middle- and high-income countries. These investments contribute to improving energy efficiency but also help reduce dependence on traditional fossil energy sources. In parallel with economic development, businesses increasingly focus on applying environmentally friendly production standards, while consumers prioritize choosing low-carbon and more ecologically responsible products.

To determine the connection between economic developments, we collected data from 27 countries in the West and South Asian regions from 2000 to 2020. In addition, we use the Driscoll Kraay standard error method (Joshi *et al*., 2021) to demonstrate the study outcomes to establish a solution for the problem of cross-sectional dependence, autocorrelation, and heteroskedasticity. Our study demonstrates a U-shaped relationship between economic growth and environmental degradation in Asian countries, comparable to Al-Mulali *et al*. (2015) and Maroufi and Hajilary (2022). In the initial stages of development, countries mainly concentrate on less energy-intensive sectors, like light industry and agriculture, with low fossil fuel consumption and CO2 emissions. However, when GDP per capita exceeds 4,126.25 USD, economic growth promotes a shift to heavy industry and energy-intensive sectors, fostering a considerable rise in the use of CO2 emissions. While the results above support the green growth theory, these do not support the pollution haven hypothesis and reject the EKC hypothesis, confirming that economic growth does not necessarily lead to environmental improvement.

Our study applies the Driscoll-Kraay Standard Estimator method compared to the traditional methods used in previous studies. This method is outstanding in dealing with potential problems related to error correlation, heterogeneous variation, and cross-sectional dependence, improving the analysis's accuracy and reliability. Our study focuses on the West and South Asia region, where unique climatic and environmental characteristics, such as deserts, mountains, and plains, make the impacts of climate change and CO2 pollution more complex and strongly affect economic development. Many countries in the region still depend on fossil energy sources, which makes the study of the relationship between economic growth and environmental degradation urgent. Limiting the scope of the study allows us to delve into the region's economic, social, and environmental characteristics, providing detailed and highly applicable results and opening up new research directions for future works.

This study makes several significant contributions to the existing literature on the relationship between economic growth and air pollution in Asian countries. First, it challenges the Environmental Kuznets Curve (EKC) hypothesis by identifying a U-shaped relationship, where initial economic growth reduces emissions, but further growth increases them beyond a certain income threshold. Second, it provides empirical evidence on the income level that marks this turning point, offering valuable insights for policymakers. Third, the study examines developing countries to identify how changes in economic growth impact CO2 emissions while ensuring the maintenance of sustainable development. Finally, it provides important implications for developing sustainable growth strategies and balancing economic development with environmental protection in the region.

The remaining sections of the report are structured as follows. The second section is the literature review. Next are the data and methods. Then, part four focuses on the study's empirical analysis, while part five will show and analyze the findings. Finally, the report will conclude with a conclusion and discuss policy implications.

2. Literature review

2.1 Theories

2.1.1 Pollution haven hypothesis (PHH). The pollution haven hypothesis explains that developed countries (with high GDP) that often have strict environmental regulations and high environmental standards may seek to shift highly polluting production activities to developing or less developed countries (with lower GDP) - where environmental regulations are lax because compliance costs are lower (Van Tran *et al.*, 2025). According to the PHH, countries with lower GDPs become "pollution havens," attracting high-emission industrial activities from rich countries. This trend often increases CO2 emissions and environmental pollution while increasing GDP (Solarin *et al*., 2017).

According to Al-Mulali and Tang (2013), developed countries that adhere to the PHH may relax environmental regulations and standards to attract investment and industrial activities. This trend may include reduced emission standards, pollution control requirements, and reduced penalties for environmental violations. With less regulatory oversight, industries might be more likely to pursue activities that result in increased air pollution. Additionally, as polluting industries move from developed countries, CO2 emissions in developing countries will increase because industries moving to developing countries often bring with them outdated or inefficient technologies in energy use and pollution control (Salehnia *et al*., 2020). Therefore, the PHH expects that economic growth positively impacts CO2 emissions.

2.1.2 Green growth theory. Green growth theory promotes sustainable economic development by combining GDP growth with environmental protection and reducing greenhouse gas emissions, including CO2 (Hao *et al*., 2021). According to this theory, countries can continue to develop their economies without harming the environment, thanks to the efficient consumption of environmental assets, the advancement of renewable energy, and the promotion of sustainable technology breakthroughs. Green growth aims to modify the traditional economy into a sustainable development model, ensuring the ability to meet current needs without depleting resources for future generations (Lorek and Spangenberg, 2014).

According to various studies (Khan *et al*., 2020; Shao *et al*., 2021), green growth emphasizes investments in eco-friendly industries and technologies that lower emissions without compromising economic development. This trend includes expanding clean energy options like wind, solar, and hydropower, as well as implementing advanced energy production and management systems, which can decrease reliance on non-renewable energy sources like fossil fuels and significantly control CO2 emissions impact on the environment (Gyamfi *et al*., 2021). Furthermore, green growth strategies advocate for sustainable business practices, shift consumption patterns, and optimize the use of resource capital. As such, this theory suggests an inverse relationship between economic growth and CO2 emissions.

2.1.3 The Environmental Kuznets Curve hypothesis (EKC). The Environmental Kuznets Curve hypothesis suggests that environmental degradation initially increases with the expansion of economics in the very first period of industrialization, primarily due to increased dependence on fossil fuels and rapid industrial expansion. As countries develop, environmental pressures increase as economic activities expand, leading to higher pollution levels, including CO2 emissions. However, the EKC suggests that as countries reach higher economic development and income levels, firms will switch to cleaner technologies and establish more stringent environmental protection policies, reducing pollution even as GDP increases (Grossman and Krueger, 1995).

As economies develop, mainly in high-income countries, structural changes occur due to increased public awareness of the environment (Panayotou, 2016). These countries tend to invest in renewable energy, improve energy efficiency, and enforce environmental regulations, facilitating the separation of economic expansion from environmental harm (Galeotti *et al*., 2006; Akça, 2024). Therefore, the EKC hypothesis suggests a non-linear relationship between GDP and CO2 emissions.

2.2 The nexus between economic growth and CO2 emissions

Several previous studies have suggested that economic growth has a positive relationship with CO2 emissions. Zhang *et al*. (2019) emphasized the inevitable relationship between GDP and pollution emissions as increased economic activities increase energy consumption, thereby increasing carbon emissions. As economic activities develop and grow, energy demand also increases. This trend increases energy production and use, especially non-renewable sources such as coal or oil. These energy sources are often accompanied by large amounts of carbon emissions into the environment. GDP growth often goes hand in hand with increased energy consumption, thereby increasing CO2 emissions (Demiral *et al*., 2021; Demiral and Akça, 2022). In addition, research by Tiba and Omri (2017) has highlighted the interconnectedness of energy consumption, economic growth, and environmental conditions at both national and regional levels, particularly in nations that attract polluting industries relocated from developed countries. A specific survey shows that energy consumption can promote economic growth through increased productivity. However, they also recognize that the emission of pollutants causes damage to the environment. This research shows that while energy consumption can promote economic progress, it has negative consequences for the environment. These research articles all support the pollution haven hypothesis.

However, some research papers also discuss the inverse relationship between economic growth and CO2 emissions. Cantore and Padilla (2010) highlight a significant link between income inequality and the distribution of emissions. Their results indicate that increased income leads to decreased CO2 emissions. Due to changes in consumption patterns, higher-income individuals favor less carbon-intensive goods and services. In addition, economic shifts toward services, increased environmental awareness, and policies targeting income inequality contribute to the observed reduction in emissions as income increases. Liu (2005) points out that less-developed countries often need more resources and modern technology to protect the environment. Economic growth is an important means to address environmental problems. As these countries achieve economic growth, they have more resources and financial capacity to invest in environmental protection measures and technological improvements. This trend may involve funding wastewater treatment facilities, advancing renewable energy projects, enhancing transportation systems to lower emissions, and supporting sustainable farming practices. By doing so, developing nations can achieve sustainable economic development while reducing adverse environmental effects. The above research articles all comply with the green growth theory.

In previous studies on air pollution, many methods have been used, such as OLS (Demiral *et al.*, 2021), FMOLS (Zhang *et al.*, 2019), Integrated Assessment Models (Cantore and Padilla, 2010), and Literature Survey (Tiba and Omri, 2017). However, no study has applied the Driscoll-Kraay method to analyze data in 27 West and South Asian areas from 2000–2020. While the Driscoll-Kraay Standard Estimator technique can handle temporal autocorrelation, heteroskedasticity does not require specific assumptions about the correlation structure or cross-correlation between units. Based on previous studies relevant to the association between economic development and CO2 emissions, the report proposes the following hypothesis:

H1. Economic growth has a negative relationship with CO2 emissions

2.3 The non-linear relationship between economic growth and CO2 emissions

Previous studies have found a U-shaped relationship between economic growth and environmental pollution (Al-Mulali *et al.*, 2015; Maroufi and Hajilary, 2022). In the early stages of economic development, countries tend to focus on industry sectors that need less demand for natural energy, such as light industry and agriculture, which have low fossil fuel consumption and negligible CO2 emissions per unit of output. In addition, technological advances and improvements in production processes help improve energy efficiency, contributing to reducing emissions. However, once the economy attains a specific stage of development, the shift to heavy industries and sectors with high energy demand becomes evident. Due to their production characteristics, these sectors consume more resources and emit significant amounts of CO2, leading to a rapid increase in emissions. When the economy is on the way to its expansion in the advanced stages, the consumption of energy capital and CO2 emission is coevolution, which reflects the significant effects of economic growth on the environment.

However, several studies have identified the Kuznets Curve correlation between economic growth and environmental pollution (Ulucak and Bilgili, 2018; Shahbaz *et al.*, 2020). During the starting phases of economic advancement, swift industrialization and urbanization frequently result in higher pollution levels, as the focus tends to be maximizing production efficiency rather than safeguarding the environment. However, once the economy achieves a specific stage of development, a shift to cleaner technologies and energy occurs. Innovation in renewable energy, stricter environmental regulations, and awareness of sustainable development help reduce pollution per unit of GDP. In addition, the study by Bilgili *et al.* (2021) also verified the EKC hypothesis in Asian areas. As health spending increases, environmental quality improves and CO2 emissions decrease, thanks to investments in health infrastructure, green technology, and environmental protection policies. This finding supports the idea that at further advanced periods of development, economic growth contributes to mitigating adverse environmental effects (Bilgili *et al.*, 2021).

Previous studies have analyzed the relationship between GDP and Carbon emissions in Asia as well as in low- and high-income countries using various methods such as FMOLS (Bilgili *et al.*, 2021) and ARDL (Al-Mulali *et al.*, 2015; Maroufi and Hajilary, 2022; Shahbaz *et al.*, 2020). However, no study has applied the Driscoll-Kraay method to effectively handle issues such as autocorrelation, heteroskedasticity, and cross-unit correlation. Based on previous studies on the non-linear correlation between economic growth and emissions, the report hypothesizes:

H2. Economic growth and CO2 emissions have a U-shaped relationship

3. Data and methodology

3.1 Data

Our research collects required indicators from World Bank databases to ensure accuracy and reliability. The data sample includes 27 countries in the two regions, West Asia and South Asia, from 2000 to 2020. Appendix B shows the list of countries included in the study. We focus our research on these two regions instead of all of Asia because these regions often have typical climate characteristics and geographical environments, such as deserts, mountains, and plains. Climate change and pollution from CO2 can have complex impacts on these natural environments, affecting economic development. Many countries in the region still rely heavily on mineral fuel sources such as oil, coal, and gas. We follow Tran *et al.* (2023) to remove some observations with unsatisfactory data to calculate the necessary variables intensely. After eliminating some surveys with insufficient data and relying on Duong *et al.* (2023), all continuous variables were winsorized at the 1% and 99% levels to minimize outlier effects. The outcome is a disruption panel with 329 observations from 27 regions.

3.2 Variable definitions

3.2.1 Carbon dioxide (CO2) emissions. We use the dependent variable CO2 emissions, which has been widely used in previous studies as an alternative measure of environmental pollution. According to Climate Tracker GHG Emissions, the significant increase in greenhouse gasses is mainly due to carbon dioxide emissions (CO2), the main gas driving global warming and climate change. As CO2 emissions increase, the environmental and climate impact is severely affected. An increase in CO2 can lead to the greenhouse effect, where CO2 absorbs heat from the ground and traps it in the air, causing global warming. We follow Tran *et al.* (2023) to take the natural logarithm of the CO2 per capita.

3.2.2 Economic growth (GDP per capita). Hao *et al.* (2021) said the GDP per capita has a significant economic impact on environmental degradation. Higher economic achievements when maximizing economic development must come with the consequences of environmental pollution. We follow Tran *et al.* (2023) to take the natural logarithm of Gross domestic product per capita.

3.3 Model constructions

Model 1, we follow Zhang *et al.* (2019) to examine the relationship between economic growth and CO2 emissions. We build model 1 to test Hypothesis 1 as follows:

$$\textit{Model 1}: \mathrm{LNCO2}_{\mathrm{i,t}} = \alpha + \beta_1 \mathrm{lNGDP}_{\mathrm{i,t}} + \beta_2 \mathrm{CONTROL}_{\mathrm{i,t}} + \alpha_{\mathrm{i}} + \alpha_{\mathrm{t}} + \varepsilon_{\mathrm{i,t}} \tag{1}$$

In model 2, we follow the empirical studies of Ulucak and Bilgili (2018) on the non-linear relationship between GDP and CO2 emissions to test Hypothesis 2 as follows:

$$\textit{Model 2}: LNCO2_{i,t} = \alpha + \beta_1 \mathrm{lN}GDP_{\mathrm{i,t}} + \beta_2 \mathrm{lN}GDP_{\mathrm{i,t}}\_SQUARED + \beta_3 CONTROL_{i,t} + \alpha_{\mathrm{i}} + \alpha_{\mathrm{t}} + \varepsilon_{i,t} \tag{2}$$

Where "$\boldsymbol{\alpha_i}$" is the country fixed effect, "$\boldsymbol{\alpha_t}$" is the year fixed effect, "α" is the intersection, and "ε" is the error term. In addition, Appendix A reports all the variable definitions.

3.4 Estimation methodology

We began by computing descriptive statistics, including mean, median, standard deviation, and correlation level of multicollinearity. Following Opoku-Mensah *et al.* (2024) and Bilgili *et al.* (2019), we conducted tests for cross-sectional dependence, unit roots, and cointegration. CIPS and CADF methods were used to assess spurious relationships. At the same time, Pedroni cointegration was chosen for its robustness with small samples, avoids common problems in other cointegration tests, and does not require specific distributional assumptions for the data.

Next, we followed Duong *et al*. (2022) to perform Hausman and Redundant tests, selecting the optimal model among OLS, FEM, and REM. A Wald test was also conducted to address variable error variance. We performed the Wooldridge test for autocorrelation to test the existence of autocorrelation in the errors of the regression model. When homoscedasticity and no correlation between error terms across observations is violated, conventional estimators can become inefficient, and their standard errors can be biased, leading to unreliable Hypothesis tests. Therefore, we run the Driscoll Kraay Standard Estimator model when cross-sectional dependence, autocorrelation, and heteroskedasticity between observations occur (Opoku *et al*., 2022). Driscoll and Kraay can produce estimates closer to the actual parameter values. Finally, we follow Duong *et al*. (2023) to estimate the turning point from the non-linear nexus between economic growth and environmental degradation as

$$\text{Turning point} = \left|\beta_1 \text{lN}GDP_{i,t} \,/\, 2 * \beta_2 \text{lN}GDP_{i,t}\_SQUARED\right|$$

4. Empirical results

4.1 Descriptive statistics

Table 1 offers the descriptive statistics for each variable in the study. The research sample was collected from 27 West and South Asian countries, including 329 observations from 2000 to 2020. Research results show that the average value of the CO2 index is 4.755, with a standard deviation of 0.734. This index shows that the level of CO2 in the air is at an average level, reflecting not too severe air pollution in the two regions of West Asia and South Asia, with the most extensive CO2 index in India (6.334) and the smallest in Bhutan (2.921). On the other hand, the average value of GDP is determined to be 3.648, which shows that the level of fluctuation of GDP and the fluctuation around the average value is low, emphasizing the less dispersion of the data, as evidenced by illustrated by a standard deviation of 0.598, the GDP index is largest in Qatar (4.858) and smallest in Afghanistan (2.611). Besides, countries in these two regions have average TRADE, UR, IND, and IP indexes of 0.744%, 0.593%, 0.325%, and 2.175, respectively.

4.2 Pearson correlation matrix

Table 2 illustrates the correlation levels of the variables according to the sample data collected. Table 2 reports a positive nexus between economic development and CO2 emissions. In addition, the remaining variables, including TRADE, UR, and IND, also have positive correlations, except IP, which has a negative correlation. The highest correlation between the two variables is UR and GDP at 0.824, showing a relatively strong positivity. To evaluate

Table 1. Summary statistics

	Mean	Median	Maximum	Minimum	Std. dev	Observation
LNCO2	4.755	4.703	6.334	2.921	0.734	329
LNGDP	3.648	3.618	4.858	2.611	0.598	329
TRADE	0.744	0.695	1.715	0.248	0.358	329
UR	0.593	0.631	1	0.171	0.242	329
IND	0.325	0.277	0.733	0.1	0.141	329
IP	2.175	2.083	4.189	0	1.008	329

Note(s): The sample has 329 observations in West and South Asian countries from 2000 to 2020. Variable definitions are in Appendix A

Source(s): Authors' calculations

Table 2. Pearson correlation matrix

Variables	LNGDP	TRADE	UR	IND	LNIP	VIF
LNGDP	1.000 –					3.328
TRADE	0.552*** (<0.001)	1.000 –				2.278
UR	0.824*** (<0.001)	0.529*** (<0.001)	1.000 –			3.409
IND	0.263*** (<0.001)	0.238*** (<0.001)	0.249*** (<0.001)	1.000 –		1.091
IP	−0.068 (0.218)	−0.502*** (<0.001)	0.010 (0.861)	−0.060 (0.277)	1.000 –	1.558

Note(s): The sample has 329 observations in West and South Asian countries from 2000 to 2020. Variable definitions are in Appendix A. Significance: *$p < 0.10$, **$p < 0.05$, ***$p < 0.01$
Source(s): Authors' calculations

multicollinearity in the data sample, we use Variance Inflation Factor (VIF) to test the strength of the correlation matrix between variables. Table 2 shows VIF values ranging from 1.091 to 3.409, with a median of 2.278, which mostly confirms no issues relevant to multicollinearity between independent variables. The above values are less than 5, showing that the model does not suffer from multicollinearity, as mentioned in the study of Duong *et al.* (2022).

Table 3 shows the CD-test results of the model. We use Pesaran (2021) for each variable. The results indicate that all variables are significant and show that the data are cross-sectionally dependent.

After the cross-sectional dependence data, we used the cross-sectionally augmented panel unit root test (CIPS) tests (Pesaran, 2007) and Pesaran's cross-sectional augmented Dickey-Fuller test (PESCADF) in order to determine the stationarity of each variable. Table 4 shows the unit root results and the order of integration analysis of the data set. The unit root tests provided statistically significant evidence to reject the null hypothesis for all variables, indicating stationarity at either level I(0) or I(1). However, urbanization has no unit root according to the CADF test.

Table 5 reports the Pedroni (1999) cointegration test results, with Phillips-Perron and Augmented Dickey-Fuller tests significant at $p < 0.05$, providing evidence to reject the null hypothesis of no cointegration. This finding suggests a long-term cointegrated relationship among the variables (Bilgili *et al.*, 2021, 2023).

Table 3. Cross-sectional dependence test

Variables	CD-test	*p*-value
LNCO2	46.587	0.000***
LNGDP	62.254	0.000***
LNGDP_SQUARED	61.719	0.000***
TRADE	6.255	0.000***
UR	50.697	0.000***
IND	18.609	0.000***
IP	2.932	0.003***

Note(s): The sample has 329 observations in West and South Asian countries from 2000 to 2020. Variable definitions are in Appendix A. Significance: *$p < 0.10$, **$p < 0.05$, ***$p < 0.01$
Source(s): Authors' calculations

Table 4. Unit root test

Variables	CIPS	CADF
LNCO2	−2.085*	−3.638***
LNGDP	−2.389***	−7.748***
LNGDP_SQUARED	−2.373***	−7.257***
TRADE	−10.522***	−3.487***
UR	−16.393***	−1.396
IND	−3.754***	−9.27***
IP	−12.023***	−4.52521

Note(s): The sample has 329 observations in West and South Asian countries from 2000 to 2020. Variable definitions are in Appendix A. Significance: **p* < 0.10, ***p* < 0.05, ****p* < 0.01

Source(s): Authors' calculations

Table 5. Pedroni residual cointegration test

	Statistic	Prob	W. statistic	Prob
Panel v-statistic	0.231	0.397	−1.783	0.963
Panel Rho-statistic	3.240	0.999	3.395	0.999
Panel PP-statistic	−2.943	0.001	−4.144	0.000
Panel ADF-statistic	−1.661	0.0048	−2.725	0.003
Panel Rho-statistic	4.725	1.000		
Panel ADF-statistic	−4.931	0.000		
Panel PP-statistic	−3.061	0.001		

Note(s): The sample has 329 observations in West and South Asian countries from 2000 to 2020. Series: LnCo2, LnGDP, LnGDP-Square, TRADE, UR, IND, IP. Variable definitions are in Appendix A

Source(s): Authors' calculations

4.3 Regression results

Table 6 presents the results of CO2 index estimates for West and South Asian countries. We perform detailed tests for each model, such as the Hausman, Redundant, and Breush–Pagan tests, to choose the most effective method (Le *et al.*, 2024). After conducting the required tests, we decided to use the Fixed Effect Model (FEM) method for all models because FEM fully meets the requirements of the tests, with the *P*-values of the Redundant test and the Hausman test being less than 5%. After that, we continued to perform the Wald and Wooldridge tests to check for unobserved heteroskedasticity and autocorrelation issues for all models. The results shown in Table 6 show that the FEM method does not overcome the problems of autocorrelation, heteroskedasticity, and heterogeneity in the models. Therefore, we follow Joshi *et al*. (2021) to use the Driscoll Kraay method to solve these problems.

We conducted the Driscoll–Kraay regression model to address the asymmetry and serial correlation. The regression results using the Driscoll–Kraay Standard Estimator method in Table 7 show that the model effectively addresses heteroskedasticity, autocorrelation, and cross-sectional dependence, ensuring robust and reliable estimates. Furthermore, the adjusted R-squared value of 0.641 demonstrates that the model explains a significant proportion of the variance in the dependent variable.

5. Discussion

Table 7 reports that higher GDP growth rates are associated with lower CO2 emission levels. In particular, based on the estimated calculation of model 2 in Table 7, the GDP index shows at

Table 6. Regression results using the fixed-effect model

Variables	Model 1	Model 2
LNGDP	0.267*** (<0.001)	0.75*** (<0.001)
LNGDP_SQUARED		−0.071*** (0.0042)
TRADE	0.192*** (<0.001)	0.182*** (<0.001)
UR	1.591*** (<0.001)	1.491*** (<0.001)
IND	0.054 (0.546)	0.049 (0.582)
IP	0.052*** (0.0001)	0.057*** (<0.001)
C	2.565*** (<0.001)	1.831*** (<0.001)
R-squared	0.993	0.994
Adjusted *R*-squared	0.993	0.993
F-statistic	1593.87	1576.731
Prob(*F*-statistic)	<0.001	<0.001
Durbin–Watson	0.380	0.379
N	329	329
Wald test	<0.001	<0.001
Wooldridge test	<0.001	<0.001
Hausman test	<0.001	<0.001
Redundant fixed-effect test	<0.001	<0.001
Country-fixed effect	Yes	Yes
Year-fixed effect	Yes	Yes

Note(s): Table 6 represents the estimation results from FEM. The sample has 329 observations in West and South Asian countries from 2000 to 2020. Variable definitions are in Appendix A. Significance: $*p < 0.10$, $**p < 0.05$, $***p < 0.01$

Source(s): Authors' calculations

Table 7. Driscoll–Kraay standard estimator

Variables	Model 1	Model 2
LNGDP	0.131*** (0.001)	−3.254*** (0.003)
LNGDP_SQUARED		0.450*** (0.001)
TRADE	−0.472* (0.049)	−0.407 (0.113)
UR	0.257* (0.046)	0.342*** (0.009)
IND	1.580*** (<0.001)	1.565*** (<0.001)
IP	0.438*** (<0.001)	0.489*** (<0.001)
C	3.009*** (<0.001)	8.998*** (<0.001)
N	329	329
Number of groups	24	24
F	2924.57	4727.87
lag	2	2
R-squared	0.601	0.641
Root MSE	0.468	0.444
Turning point		4126.25

Note(s): The sample has 329 observations in West and South Asian countries from 2000 to 2020. Variable definitions are in Appendix A. Significance: $*p < 0.10$, $**p < 0.05$, $***p < 0.01$

Source(s): Authors' calculations

(−3.254), indicating that when the GDP's economic growth rate rises by 1%, the CO2 emission rate goes down by 3.254%. This finding suggests that economic development is an approach to alleviating environmental pressures. When countries achieve economic growth, they have more resources and financial capacity to invest in environmental protection measures and technological innovation. These investments include developing wastewater treatment systems, developing renewable energy sources, improving transportation infrastructure to reduce emissions, and promoting sustainable agriculture. The report's results are consistent with the findings of Liu (2005) and Cantore and Padilla (2010). However, this result contradicts Zhang *et al*. (2019) and Tiba and Omri (2017) due to the close relationship between economic development and energy consumption, which is often produced from fossil fuel sources such as oil, coal, and gas. Since the economy grows, the energy demand also increases, which leads to a higher demand for fossil fuel sources. Producing and transporting products also requires energy, contributing to increased CO2 emissions. This finding supports the green growth theory and Hypothesis 1. According to this theory, countries can continue growing their economies without harming the environment by efficiently using natural resources, developing renewable energy, and encouraging innovation of green technology. However, it does not support the pollution haven hypothesis since the idea suggests that the majority of developed regions that have strict environmental regulations and standards may take their industries that are relevant to manufacturing into other developing countries that have less concern for environmental regulations, which will progressively create a room for increasing CO2 emissions and environmental pollution for these areas.

Table 7 also indicates a non-linear relationship between economic growth and environmental quality. The result indicates that when GDP increased by 1%, CO2 emissions decreased by 3.254%. However, when GDP per capita growth exceeded the threshold (4,126.25 USD), environmental pollution increased accordingly. Specifically, after exceeding the threshold, 1% GDP per capita growth increased CO2 by 0.45%. In the starting stages of economic development, countries tend to focus on less energy-intensive industries, like light industry and agriculture, which have low fossil fuel consumption and negligible CO2 emissions per unit of output. In addition, technological advances and improvements in production processes help improve energy efficiency, contributing to reducing emissions. However, when the economy reaches a certain level of development, the shift to heavy industries and sectors with high energy demand becomes evident. Due to the nature of their production, these industries consume more resources and emit significant amounts of CO2, leading to a rapid increase in emissions. In the following stages, as the economy continues to expand, energy consumption and CO2 emissions also increase, reflecting the influence of economic growth on the surrounding environment (Al-Mulali *et al*., 2015; Maroufi and Hajilary, 2022). Therefore, to limit this negative impact, economic development policies must be adjusted to maintain a stable growth rate at the threshold (4,126.25 USD), helping minimize CO2 emissions and prevent environmental pollution. Our results show a U-shaped relationship between economic growth and CO2 emission rate, reinforcing the second hypothesis and rejecting the EKC hypothesis.

6. Conclusion

This article examines the connection between economic growth and air pollution. We use gross domestic product (GDP) to measure economic growth and CO2 emissions to represent a measure of environmental pollution. We use a data sample of 27 countries in the Asian region during the period from 2000–2020. The final data sample obtained includes 329 annual observations. We use the Driscoll Kraay Standard Estimator method to overcome the cross-sectional dependence, heteroskedasticity, and autocorrelation issues. The findings report a U-shape between economic growth and air pollution, with a turning point of 4,126.25 USD. Although these findings are consistent with the green growth theory, they do not help much with the pollution haven hypothesis and reject the EKC hypothesis.

Our study provides policymakers and economic operators with rich empirical evidence on new strategies for sustainable local economic development without environmental problems. First, policymakers can use the outcomes of this investigation to identify the threshold of economic development that minimizes environmental degradation. To balance economic expansion with environmental preservation, the government must develop appropriate policies to control CO2 emissions when GDP per capita exceeds the threshold of 4,126.25 USD. This level of sustainable growth protects the ecosystem. It promotes businesses and communities to transition to a green economy, raise environmental awareness, and move towards a circular and sustainable production and consumption model.

Second, priority should be given to promoting less energy-intensive economic sectors while encouraging technological innovation and improving energy efficiency. In addition, the government can adopt environmental tax and fee policies to limit fossil fuel consumption, such as imposing higher taxes on heavy industries with high emission levels and encouraging investment in renewable energy. In addition, supporting businesses in transitioning to green production models and implementing programs to encourage the use of clean technology will help maintain sustainable economic growth without increasing pollution. Moreover, stricter environmental controls, such as emissions monitoring and carbon quotas, can help countries maintain economic growth while ensuring their commitment to reducing CO2 emissions.

In addition to adjusting economic development policies, the government needs to increase investment in research and application of green technology to reduce the environmental impact of GDP growth. Specifically, financial support and tax incentives for enterprises applying energy-saving and cleaner production technologies will help limit CO2 emissions during the high growth period. At the same time, the government can establish investment funds for renewable energy, encouraging innovation initiatives in energy storage and more efficient use. In addition, it is necessary to strengthen international cooperation in sharing technology and environmental management experience, thereby helping countries maintain stable economic growth without increasing pollution. The close combination of economic development, technological innovation, and environmental policy will ensure a sustainable growth model, harmonizing economic benefits and ecosystem protection.

Although this study contributes to the growing literature on environmental economics, several limitations warrant consideration: it focuses exclusively on CO_2-emitting pollutants rather than the full spectrum of greenhouse gases, overlooks critical contextual determinants such as geographical heterogeneity, technological innovation and eco-awareness campaigns, and draws upon data from only West and South Asia, thereby constraining external validity. Methodologically, the Driscoll–Kraay estimator, while helpful in addressing cross-sectional dependence and heteroskedasticity, relies on a relatively large time dimension and may underperform in panels with limited sampling periods or latent hierarchical structures, potentially yielding efficiency losses or model misspecification. By contrast, Bayesian regression techniques offer distinct advantages: the incorporation of informative priors enhances parameter estimation under data scarcity; posterior distributions provide richer uncertainty quantification; hierarchical and spatial models can flexibly capture regional and temporal dependencies; and model comparison via Bayes factors facilitates rigorous specification testing (Thach *et al.*, 2022). Future research should, therefore, adopt Bayesian panel regression frameworks, extending data collection across East, Central, and Southeast Asia to harness these methodological strengths, thereby producing more precise, credible, and policy-relevant insights into the nexus between economic growth and environmental quality.

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Ethical statement

This article contains no studies with human or animal participants.

Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Declaration of generative AI in scientific writing

In preparing this manuscript, the author used Scispace to conduct systematic literature reviews and propose relevant policy implications. Moreover, the authors also use Grammarly to improve spelling, grammar, and general editing. Prior to submission, the authors reviewed the content generated and took full responsibility for the content of the submitted manuscript.

Supplementary material

The supplementary material for this article can be found online.

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