International Journal of Environmental and Ecology Research
www.environmentaljournal.in
Online ISSN: 2664-7117
Received: 06-01-2026, Accepted: 05-02-2026, Published: 20-02-2026
Volume 8, Issue 1, 2026, Page No. 32-39

Economic growth, renewable energy consumption, and FDI on greenhouse gas emissions in South Asia: Evidence from the pollution haven hypothesis

A I S Perera
Lecturer in Business Statistics, Department of Social Statistics, University of Sri Jayewardenepura, Sri Lanka

Abstract
The rapid growth of foreign direct investment has corresponded with a gradual rise in greenhouse gas emissions across South Asia, prompting concerns about the environmental consequences of cross-border capital flows. Thus, this study investigates the long- and short-term effects of economic growth, renewable energy consumption, and foreign direct investment (FDI) on greenhouse gas (GHG) emissions in South Asia, with an emphasis on the Pollution Haven Hypothesis (PHH). The analysis uses annual panel data of Bangladesh, India, Pakistan, and Sri Lanka from 1972 to 2022, as well as panel unit root tests, panel cointegration techniques, and panel autoregressive distributed lag (ARDL) models, which include pooled mean group (PMG), mean group (MG), and dynamic fixed effects (DFE) estimators. The positive and statistically significant effect of FDI on emissions provides significant empirical evidence to the Pollution Haven Hypothesis, which states that South Asian countries attract pollution-intensive foreign direct investment due to weaker restrictions on pollution. These findings emphasize the ecological risks of unregulated FDI inflows, emphasizing the significance of incorporating environmental safeguards into investment and energy policies to achieve sustainable development in South Asia.

Keywords: Greenhouse gas emission, foreign direct investment, panel ardl, pollution haven hypothesis

Introduction

Greenhouse gas (GHG) emissions have emerged as a major policy concern in emerging countries experiencing rapid economic growth and greater integration into global capital markets. South Asia, in particular, has seen a consistent rise in GHG emissions in recent decades, driven by industrial growth, higher demand for energy, and increased foreign direct investment (FDI). While foreign investment is largely viewed as an element on growth in the economy, implications for greenhouse gas emissions are still being debated.

South Asia as a region has experienced substantial economic expansion and progress, but this has frequently come at cost of growing environmental degradation. (Sattar *et al*. 2022) [12]. Thus, rapid economic growth and industrialization in South Asian countries have resulted into increasing energy consumption and foreign direct investment. While these advancements have accelerated economic growth, they have also contributed to increased greenhouse gas emissions, which pose serious challenges to environmental sustainability and public health.

The rapid increase in GHG emissions poses a severe risk to the environment, ecosystems, and human society. In response to this concern, the UN Framework Convention on Climate Change (UNFCCC) was established to address climate change on a global basis. The major solution to combating climate change is to decrease GHG emissions, that many countries are adhering to doing through agreements like the Kyoto Protocol. Furthermore, a recent call has been made for a global commitment to achieving net zero emissions by 2050. (Mikhaylov *et al*, 2020).

The Pollution Haven Hypothesis (PHH) is a significant theoretical paradigm for explaining the relationship between foreign direct investment and emissions. According to the PHH, multinational corporations relocate pollution-intensive production operations to countries with poor environmental restrictions, boosting emissions in the host economy. This argument is especially pertinent for South Asian countries, because regulatory enforcement capacity may fall behind economic objectives (Singhania and Saini 2021) [26].

Despite rising demand in the investment-emissions nexus, evidence focused primarily on greenhouse gas emissions within a PHH framework is limited in South Asia (Kim *et al*., 2020). Many existing research focus on income-related hypotheses or consider foreign direct investment as a secondary explanatory variable, without adequately distinguishing between short-run and long-run dynamics. Furthermore, the importance of renewable energy consumption in reducing the emission effects of foreign investment has not received adequate consideration. This study addresses these gaps by examining the impact of foreign direct investment, economic growth, and renewable energy consumption on greenhouse gas emissions in Bangladesh, India, Pakistan, and Sri Lanka from 1972 to 2022, both individually and as a panel. The secondary data source is the World Bank Development Indicator (WDI). The analysis utilizes a panel autoregressive distributed lag (ARDL) framework to capture both short-run adjustments and long-run equilibrium relationships.

The primary objective is to empirically test the Pollution Haven Hypothesis and determine whether foreign investment inflows contribute to higher emissions levels in South Asia. The current study provides targeted insights into the climate implications of economic growth and investment patterns in South Asia and the current study will specifically discuss how the findings relate to Sustainable Development Goals (SDG) 13 (Climate Action) and 11 (Sustainable Cities and Communities), along with policy recommendations for reducing GHG emissions while encouraging economic growth.

The deteriorating climate could be attributed to governments enacting unsustainable economic policies that endanger both

humans and the ecosystem. Policymakers frequently prioritize economic growth over environmental quality. To address this, sustainable economic growth must become a key priority for governments, whether in developed or developing countries. Balancing economic growth with goals for improving environmental quality and reducing environmental damage is crucial for achieving sustainable development.

Countries in the South Asian region must meet the SDGs enforced by the United Nations by 2030. It is critical to recognize the relationship between financial, economic, and environmental stability. There are few studies that investigate the relationship between environmental, financial, and financial factors and emission in the South Asian region.

As a result, the current study provides useful insights for policymakers and authorities working to achieve sustainable development in the region, which can help establish policies that promote SDGs while simultaneously addressing climate change challenges. Furthermore, this study will add to the academic literature on environmental economics, particularly in the context of South Asia, which has been underrepresented in prior studies.

The paper's remainder is organized as follows: Section 2 presents data, sources, and the methodology of the study. Section 3 includes the interpretation of results and discussion. The last section concludes the study.

Pollution Haven Hypothesis and Environment Sustainability

The PHH is an economic theory suggesting that industries, particularly those involved in manufacturing and production, may relocate from countries with strict environmental regulations (developed countries) to countries with less stringent regulations (developing countries). This relocation is believed to take place in an effort to reduce production costs associated with environmental compliance(Minier, 2023.).

The PHH implies that multinational corporations (MNCs) tend to shift their manufacturing to countries with less stringent environmental restrictions, resulting in increased pollution in these "pollution havens." This issue occurs as businesses attempt to decrease manufacturing expenses, especially those involved with meeting environmental standards in more developed countries. The hypothesis states that as a result, developing countries or countries with weaker environmental policies may experience increased levels of pollution as they become attractive destinations for ecologically destructive enterprises.

The PHH predicts that disparities in pollution regulation will be the key element determining a country's competitive advantage. Trade causes less developed nations to specialize in the manufacturing of dirty commodities, which become dirtier as a result of low environmental standards. Developing countries typically set lower standards for three main reasons.

Initially, poorer countries face higher costs for pollution monitoring and norm enforcement. This is due to (in comparison to developed countries) a lack of skilled labor, high implementation costs for new environmental regulations, difficulties obtaining updated equipment, and corruption. Second, there is a greater demand for clean air and water in developed countries with high incomes. Low-income developing countries are more concerned with providing jobs and increasing income than with pollution and health.

Third, the growth of developing countries indicates an alteration in focus from agriculture to manufacturing. This leads to rapid urbanization and significant investments in urban infrastructure, ultimately increasing pollution. In contrast, growth in developed economies indicates a shift away from industry and toward services, which reduces pollution intensity. (Bhat and Tantri, 2023) [4].

The contrast between pollution haven theory and pollution haven effect is critical. The pollution Haven Effect is a reduction in trade costs that causes the production of pollution-intensive commodities to shift to countries with lower environmental standards. An improvement in environmental standards reduces exports of polluting goods or increases imports. (Singhania, Saini 2021).

According to the pollution-haven hypothesis, foreign direct investment is drawn to the host country's poor environmental and regulatory policies. As a result, FDI is likely to have a negative impact on the environment, particularly in emerging markets with poor environmental standards. In reality, some countries are eager to attract foreign direct investment and may compete in a "FDI tournament" by enforcing inadequate environmental laws.

The pollution-halo theory contends that foreign companies, particularly those from established economies, bring with them improved management capabilities and newer, cleaner technology, which can improve the host country's environmental quality. When local enterprises are perceived to be polluting more than international standards, the pollution-halo hypothesis becomes more relevant. (Polloni-Silva *et al*, 2021) [18].

Materials and Methodology

Data and Variables

The analysis uses annual panel data for four South Asian countries namely Bangladesh, India, Pakistan, and Sri Lanka from 1972 to 2022. Data are sourced from the World Bank's World Development Indicators. The dependent variable is greenhouse gas emissions, which are given as metric tons of CO_2 equivalent. Foreign direct investment inflows (measured as a percentage of GDP) are the main explanatory variable, as they are directly related to the Pollution Haven Hypothesis. Real GDP per capita serves as a proxy for economic growth, whereas renewable energy consumption measures the proportion of energy derived from renewable sources. All variables are transformed into natural logarithms to stabilize variance and facilitate elasticity-based interpretation.

An Empirical Model of The Study

This study also developed an empirical model that corresponds to research conducted by Djellouli *et al*., (2022) [6], Irfan & Ojha, (2022) [8], Irfan & Ojha, (2022) [8],.Zardoub, (2021) [26],Nazah *et al*., (2021) [15], Banday & Aneja, (2019) [3], Bergstresser, (2018.), Abidin *et al*., (2015), Acaravci & Ozturk, (2010) [2],

The model can be stated in the following functional form,

$$GHG = f(EC, GDP, FDI) \quad (1.1)$$

The empirical model of the study indicates that greenhouse gas emissions (GHG), are a function of energy consumption (EC), per capita gross domestic production (GDP), and net

inflows of foreign direct investment, (FDI), in Selected countries.

This Panel ARDL approach was selected as it is appropriate irrespective of whether the variables are integrated of order either I (0), I (1), or a combination of both, additionally, it allows for the examination of both short and long run repercussions. The experimental model of ARDL (p, q, q,…, q) developed by Pearsan *et al*. (1999) is formulated as follows.

$$Y_{it} = \sum_{j=1}^{p} \lambda_{ij} Y_{i,t-j} + \sum_{j=0}^{q} \delta'_{1ij} X_{1,t-j} + \sum_{j=0}^{q} \delta'_{2ij} X_{2,t-j} + \sum_{j=0}^{q} \delta_{3ij} X_{3,t-j} + \sum_{j=0}^{q} \delta'_{ij4} X_{4,t-j} + \mu_i + \varepsilon_{it} \quad (1.2)$$

Where $x_{i,t}$ are $(k \times 1)$ represented the vector of explanatory variables(EC,GDP,FDI) for group i, $\delta'_{i,t}$ are $(k \times 1)$ denoted the coefficient vectors of the regressors $y_{i,t}$ is the dependent variable (GHG), $\lambda_{i,t}$ represent the coefficients of the lagged dependent variables and μ_i denotes the fixed effects, $i = 1,2,.....,N$ and $t = 1,2,.....,T$.

Method of Analysis

The empirical strategy follows a systematic panel data approach. First, panel unit root tests are conducted to assess the stationarity properties of the variables. Levin–Lin–Chu and Breitung t-stat are applied to ensure robustness across alternative specifications. This step is particularly important because many macroeconomic data sets tend to be non-stationary (Verick 2018). A time series is considered stationary if its mean and autocovariance are constant across time (Venkatesan and Ponnamma 2017). The unit root test is employed to investigate the sta1tionarity and determine the order of integration of all respective variables, considered in the current study, it is needed to identify whether the series is integrated with the order I (0) or I (1). If the variables are a mix of I(0) and I(1) or all I(1), then the panel ARDL model can be appropriately estimated (Zardoub 2021) [26].

Second, panel cointegration tests are applied to examine the presence of a long-run equilibrium. Cointegration implies that although individual variables may be non-stationary (they have unit roots), there is a stationary linear combination of these variables. This demonstrates the presence of a long term equilibrium relationship among the variables. To investigate the existence of the relationship in the long run, the current study applied the panel cointegration test suggested by Pedroni (1999, 2004).

Third, panel ARDL models are estimated using the pooled mean group (PMG), mean group (MG), and dynamic fixed effects (DFE) estimators.

Pooled Mean Group

The key attribute of PMG is its capability to accommodate heterogeneous coefficients in the short run, including intercepts, speed of adjustment to long-run equilibrium values, and error variances across countries, as well as ensuring uniform slope coefficients in the long run across countries. This flexibility is particularly advantageous when the long-run equilibrium relationship among variables is assumed to be consistent across countries or at least among a subset of them.

The short run heterogeneity adjustment enables country-specific responses to factors such as financial crises, external shocks, stabilization policies, and monetary policies. However, several conditions are crucial for ensuring the validity, consistency, and efficiency of this methodology. However, several conditions are crucial to ensure the validity, consistency, and efficiency of this methodology;

- To confirm the presence of a long-run relationship between the variables, the coefficient of the error-correction term must be negative.
- A fundamental assumption for the ARDL model's consistency model is that the residuals from the error-correction model must be free from serial correlation, and the explanatory variables should be considered exogenous.
- The relative sizes of T (time periods) and N (cross-sectional units) are critical. When both T and N are large, dynamic panel techniques can be utilized to mitigate bias in mean estimators and address issues of heterogeneity (Nazah *et al*., 2021) [15] and (Zardoub 2021) [26]

The PMG estimator allows for heterogeneity in short-run dynamics while imposing homogeneity on long-run coefficients. The Pesaran-Yamagata (2008) homogeneity test is a statistical test designed to evaluate the homogeneity of long-run coefficients in panel data models. The standard delta test and adjusted test determines if the explanatory variables' coefficients in a panel data model are consistent across all cross-sectional units (entities) within the panel. If the coefficients are found to be homogeneous, it suggests that there is a common long-run relationship among the variables across all entities. (Djellouli *et al*. 2022) [6]. The Hausman test is employed to determine the most appropriate estimator. The analysis is performed using STATA software.

Unlike other methods that utilize time series data, diagnostic tests are essential for analyzing the dynamics within a chronological "causal" framework. These tests help address the complexity of interrelationships that time series models may not fully capture. Therefore, it is essential to incorporate advanced time series techniques into the methodology to more effectively address these complexities. Therefore, The Hausman test was applied to select the most appropriate model among the PMG, MG, and DFE estimators by determining whether there were significant differences among these estimators. The Hausman (1978) test was employed to assess the effectiveness of PMG, MG, and DFE estimators. The assumption of homogeneity in the long-run policy parameters cannot be made a priori. The effect of heterogeneity on the means of the coefficients can be determined using the Hausman type of test (Chu and Sek 2014) [5]. If the null hypothesis is rejected, and the more efficient estimator MG, is preferred (Nazah *et al*., 2021) [15]. Breusch Pagan's chi-square test and Jarque and Bera test has been applied to check heteroscedasticity in the residuals of the fitted model and the normality respectively.

These tests and methods employed in the current study have been employed in numerous previous studies. For instance,

Djellouli *et al*., (2022) [6], Irfan & Ojha, (2022) [8], Irfan & Ojha, (2022) [8],.Zardoub, (2021) [26],.Nazah *et al*., (2021) [15], Banday & Aneja, (2019) [3], Bergstresser, (2018.), Abidin *et al*., (2015), Acaravci & Ozturk, (2010) [2], Acaravci & Ozturk, (2010) [2] have used most of these tests and methods in their studies.

Results and Discussion

Descriptive Statistics Analysis

The descriptive statistics of all determinants are essential for understanding the nature and characteristics of the data used in the study. A detailed overview of the descriptive statistics for all variables is shown in Table 1.

Table 1: Descriptive Statistics for the Variables

Variable		Mean	Std. Dev.	Minimum	Maximum	Observations
GHG	Overall	6394000	9693828	88532.1	40000000	N=204
	BGD	1490379	509740	169050	2603593	n = 51
	IND	21000000	9366917	10300000	40000000	n = 51
	PAK	2788473	1289929	1004660	5331729	n = 51
	SLR	331624.9	83895.13	88532.1	496731.9	n = 51
EC	Overall	2611.08	1499.16	219.05	7143.41	N=204
	BGD	1177.70	816.21	219.05	2916.32	n = 51
	IND	3579.76	1740.97	1431.49	7143.41	n = 51
	PAK	3010.37	924.75	1432.22	4683.57	n = 51
	SLR	2676.47	1163.03	1383.76	4973.60	n = 51
GDP	Overall	1186.07	902.61	349.19	4495.71	N=204
	BGD	751.50	390.03	385.71	1784.74	n = 51
	IND	869.83	523.49	349.19	2089.73	n = 51
	PAK	969.98	924.74	1432.22	4683.57	n = 51
	SLR	2153.00	1228.52	760.20	4495.71	n = 51
FDI (‘0000)	Overall	393000	1100000	-3610	6440000	N=204
	BGD	61200	87200	-801	283000	n = 51
	IND	1380000	1890000	-3610	6440000	n = 51
	PAK	131000	131000	-400	559000	n = 51
	SLR	33300	39200	-121.85	161000	n = 51

India exhibits the highest average GHG emissions 40,000,000, reflecting its large economic scale and energy-intensive production structure, while Sri Lanka has the lowest at 88,532.1. This pattern indicates India's substantial industrial activity and environmental impact. Bangladesh and Pakistan display moderate but rising emission levels. Similar disparities are observed for energy consumption and income levels, highlighting structural differences in development paths across South Asia.

FDI analysis shows India attracting the highest investment (1,380,000), indicative of its favorable investment climate, while Bangladesh, Pakistan, and Sri Lanka have much lower FDI levels, with occasional disinvestment periods as reflected by negative minimum values indicating episodes of net capital outflows. The large standard deviations associated with FDI confirm substantial temporal fluctuations, which may influence environmental outcomes. Overall, the data underscore India's dominance in emissions, energy use, and FDI, while Sri Lanka shows the highest GDP, illustrating diverse economic and environmental profiles across these countries. These variations justify the application of panel econometric techniques that account for both cross-sectional heterogeneity and dynamic adjustment processes.

Unit Root Test

The results of the panel unit root test, assuming a common unit root process, are presented in Table 4.3 and include Levin, Lin & Chu t* and Breitung t-statistics for variables GHG, EC, GDP, GDP2, and FDI at both level and first differences, considering intercept and intercept with trend presented in table 4.3. These results indicate that most variables become stationary at first differences, satisfying the necessary condition for estimating a Panel ARDL model. The combinations of I (0) and I (1) variables suggest an ARDL model is appropriate to explore the long-term relationships among GHG emanations, energy consumption, GDP, and FDI while accounting for dynamic short-term adjustments.

Table 2: Panel Unit Root Tests

Variable	Levin, Lin & Chu t				Breitung t-stat	
	Intercept		Intercept with trend		Intercept with trend	
	Level	1st diff.	Level	1st diff.	Level	1st diff.
GHG	3.8911	-10.4114	-0.7127	-14.0580	2.8572	-4.4341
p-value	1.0	0.00	0.238	0.00	0.9979	0.00
EC	3.3221	-6.9181	-0.5559	-7.7690	1.4325	-0.3710
p-value	0.9996	0.00	0.2891	0.00	0.924	0.3553
GDP	-0.2267	-22.8788	-12.3734	-	-0.6895	-
p-value	0.4103	0.00	0.00		0.0253	
FDI	-2.0634	-	-1.4400	-12.057	-2.4599	
p-value	0.0195		0.0749	0.00	0.0069	

The unit root test has the consistent rejection of the null hypothesis at the first difference for most variables suggesting that these determinants are integrated with order one, I (1). However, FDI stand out as exceptions, as they are stationary at the level, indicating that integrated of order zero, I (0). Given the presence of both I (0) and I (1) variables, the panel ARDL model is an appropriate econometric technique for estimating the relationship among these variables. This model is well suited to handle both I (0) and I (1) variables without requiring pre-transformation and allows for the examination of short and long run dynamics within the panel data structure. It can be concluded that the unit root tests, confirmed that none of the variables are integrated of order 2, I (2)

Homogeneity Test

The Pesaran and Yamagata (2008) homogeneity test indicates strong statistical significance, leading to a rejection of the null hypothesis of slope homogeneity across the panel at the 1% significance level. Specifically, both the Delta statistic and the adjusted Delta statistic strongly reject the null hypothesis. This provides compelling evidence of cross-sectional heterogeneity in the panel data, thereby justifying the use of panel heterogeneous estimation procedures.

Cointegration Test

The results of the cointegration test present in Table 4.6 indicate a significant long-term equilibrium relationship among the variables across the panel. The v-statistic is 4.2251 with a p-value of 0.000, showing strong evidence of significant cointegration. Additional statistics further support the presence of long-run association, including the panel rho statistic [−1.4388, p = 0.0751], panel t-statistic [−1.3849, p = 0.0830], and panel ADF statistic [−1.5493, p = 0.0607]. Collectively, these results confirm that greenhouse gas emissions, economic growth, renewable energy consumption, and foreign direct investment are cointegrated over the long run across South Asian countries.

Table 3: Cointegration Test

	Statistic	
Cointegration Test Statistics	**Panel**	**Group**
v	4.2251 (0.000)	
Rho	-1.4388 (0.0751)	-0.5349 (0.0963)
t	-1.3849 (0.0830)	-0.3654 (0.6426)
Adf	-1.5493 (0.0607)	-0.5424 (0.2937)

In a panel ARDL model, the dependent variable is affected by both its own and other variables the lagged values. The optimal lag structure for the panel ARDL model is determined using the Modified Bayesian Information Criterion (MBIC), Modified Akaike Information Criterion (MAIC), and Modified Quinn Information Criterion (MQIC). The results indicate that a lag length of one minimizes all selection criteria [MBIC = −315.6674; MAIC = −74.5472; MQIC = −172.2763]. Accordingly, a panel ARDL (1,1,1,1) specification is selected, ensuring parsimony while adequately capturing dynamic relationships among the variables. This suggests that the model with a single lag is the most suitable among the considered options, as it provides the best balance between model fit and simplicity across the three selection criteria. This result is also validated from the cross-correlation analysis.

Model Estimation

Table 4.8 presents the estimation results obtained using the pooled mean group, mean group, and dynamic fixed effects estimators. The error correction term (ECT) from the PMG estimator is negative and highly significant [ECT = −0.8528, p = 0.040], confirming the existence of a stable long-run equilibrium relationship. The magnitude of the ECT indicates that approximately 85% of short-run disequilibria are corrected within one period.

Table 4: Results of PMG, MG, and DFE Estimators

Variables	**PMG**		**MG**		**DFE**	
	Coefficient	**Std. Err**	**Coefficient**	**Std. Err**	**Coefficient**	**Std. Err**
Short Run						
ECT p-value	-0.8528 0.040	0.0490	-0.4123 0.002	0.1325	0.02316 0.268	0.020
D.EC p-value	1207.57 0.000	542.24	222.02 0.561	381.64	1207.578 0.00	214.60
D.GDP p-value	121.89 0.104	2534.94	-454.46 0.819	1987.38	-183.571 0.705	484.108
D.FDI p-value	-0.00002 0.186	0.00003	-0.00006 0.117	0.00003	0.00001 0.082	0.00008
Constant p-value	328375.2 0.094	196294.5	665918.6 0.091	393393.9	-22963.29 0.780	82096.2
Long Run						
EC p-value	6806.37 0.00	1335.51	1718.09 0.082	986.78	-681.07 0.857	3774.97
GDP p-value	-12911.31 0.00	3285.78	750.646 0.685	1849.13	3247.91 0.856	6071.096
FDI p-value	0.0002 0.00	0.00005	0.00021 0.117	0.0001	0.00001 0.856	0.00038

In the short run, the error correction term (ECT) under the PMG estimator is negative and statistically significant (ECT = −0.8528, p = 0.040), confirming the existence of a stable long-run equilibrium relationship and indicating that approximately 85% of deviations from equilibrium are corrected within one period. Short-run changes in energy consumption exert a positive and highly significant effect on greenhouse gas emissions (ΔEC = 1207.57, p < 0.01), highlighting the immediate environmental impact of energy use. In contrast, short-run effects of economic growth and foreign direct investment are statistically insignificant, suggesting that their environmental impacts do not materialize instantaneously.

In the long run, energy consumption has a strong positive and statistically significant effect on emissions under the PMG estimator (EC = 6806.37, p < 0.01), confirming its dominant role in driving environmental degradation. Economic growth exhibits a statistically significant negative long-run coefficient (GDP = −12911.31, p < 0.01), indicating a potential scale-to-efficiency transition consistent with structural adjustments over time. The MG and DFE estimators yield largely insignificant long-run coefficients, reinforcing the efficiency and suitability of the PMG estimator for the present panel.

Overall, the results suggest that energy consumption is the primary driver of greenhouse gas emissions in both the short and long run, while the environmental effects of economic growth and foreign direct investment are predominantly long-term and model-dependent.

Model selection is based on the Hausman specification tests comparing alternative panel ARDL estimators. The test results fail to reject the null hypothesis of long-run coefficient homogeneity, as evidenced by the insignificant test statistics for the PMG–MG comparison $(\chi^2 = 5.53, p = 0.30)$ and the PMG–DFE comparison $(\chi^2 = 0.02, p = 1.00)$. In contrast, no statistically meaningful differences are observed between the MG and DFE estimators $(\chi^2 = 0.00, p = 1.00)$. These findings support the assumption of homogeneous long-run relationships across countries. Consequently, the pooled mean group (PMG) estimator is selected as the preferred model due to its efficiency and its ability to allow for heterogeneous short-run dynamics while imposing long-run homogeneity.

The final fitted model can be written as follows.

$$\Delta GHG_{it} = 6806.37EC_{i,t} - 12911.31GDP_{i,t} + 0.0002FDI_{i,t} + 1207.57\Delta EC_{i,t-j} + 121.89\Delta GDP_{i,t-j} - 0.00002\Delta FDI_{i,t-j} - 0.8528 \quad (1.3)$$

Table 5: Short-Run Results of PMG by each Country

Variables	Bangladesh		India		Pakistan		Sri Lanka	
	Coeff.	Std. Err	Coeff.	Std. Err	Coeff.	Std. Err	Coeff.	Std. Err
ECT p-value	-0.2151 0.001	0.6548	-0.105 0.004	0.0369	-0.0178 0.030	0.0079	-0.00221 0.032	0.0010
D.EC p-value	253.107 0.701	659.71	2153.03 0.004	750.3631	564.741 0.00	114.551	-22.7975 0.613	45.05
D.GDP p-value	4774.281 0.254	4187.75	6766.14 0.003	2257.53	-2901.442 0.000	426.187	421.988 0.000	76.945
D.FDI p-value	-0.00002 0.854	0.00014	-0.00001 0.124	0.0000	0.00002 0.325	0.000022	-0.00013 0.00	0.000003
Constant p-value	776658 0.00	215916.9	538946 0.034	254366.1	3232.155 0.07	43152.31	-5335.519 0.582	9684.753

The country-specific short-run dynamics obtained from the PMG estimator provide important insights into adjustment behavior and the validity of the Pollution Haven Hypothesis (PHH) in South Asia. The error correction term (ECT) is negative and statistically significant for all countries—Bangladesh $(\text{ECT} = -0.2151, p = 0.001)$, India $(\text{ECT} = -0.1050, p = 0.004)$, Pakistan $(\text{ECT} = -0.0178, p = 0.030)$, and Sri Lanka $(\text{ECT} = -0.0022, p = 0.032)$—confirming convergence toward the long-run equilibrium following short-run disturbances.

Focusing on the PHH, the short-run coefficients of foreign direct investment (FDI) are statistically insignificant in Bangladesh $(\beta = -0.00002, p = 0.854)$, India $(\beta = -0.00001, p = 0.124)$, and Pakistan $(\beta = 0.00002, p = 0.325)$. This absence of immediate FDI-induced environmental effects suggests that pollution-haven mechanisms do not operate in the short run within these economies. Such findings are consistent with the theoretical premise of the PHH, which posits that environmental degradation arises gradually as pollution-intensive industries relocate and expand over time rather than through transitory capital inflows.

In contrast, Sri Lanka exhibits a negative and statistically significant short-run FDI coefficient $(\beta = -0.00013, p < 0.01)$, indicating that increased FDI inflows are associated with a reduction in greenhouse gas emissions. This result runs counter to the PHH and instead supports the pollution-halo hypothesis, implying that foreign investment in Sri Lanka may embody cleaner technologies, higher environmental standards, or stronger regulatory enforcement.

Overall, the short-run evidence provides limited support for the Pollution Haven Hypothesis across South Asia, reinforcing the view that pollution-haven effects, if present, are predominantly long-run in nature. Moreover, the heterogeneous response observed in Sri Lanka highlights the critical role of country-specific institutional quality and environmental regulations in moderating the environmental consequences of foreign direct investment.

Post-estimation diagnostic tests indicate that the fitted model broadly satisfies key classical assumptions. The Breusch–Pagan test fails to reject the null hypothesis of homoskedasticity $(\text{BP} = \mathbf{3.21}, \boldsymbol{p} = \mathbf{0.0734})$, suggesting constant error variance. The Pearson CD test provides marginal evidence of residual dependence $(\text{CD} = \mathbf{4.32}, \boldsymbol{p} = \mathbf{0.0583})$; while the null hypothesis of no dependence is not rejected at the 5% level, it is weakly rejected at the 10% level. In contrast, the Jarque–Bera test strongly rejects the normality assumption $(\text{JB} = \mathbf{270.3}, \boldsymbol{p} < \mathbf{0.01})$. Overall, although heteroskedasticity does not appear to be a concern, the presence of weak residual dependence and non-normality

justifies the use of robust inference to ensure reliable estimation.

Conclusion and Recommendations

This study examines the environmental implications of economic growth, renewable energy consumption, and foreign direct investment (FDI in South Asia within the framework of the Pollution Haven Hypothesis (PHH), employing a panel ARDL methodology using the pooled mean group (PMG) estimator. The findings provide robust evidence that long-run environmental outcomes in South Asia are strongly influenced by energy consumption patterns and foreign investment dynamics, while short-run effects remain highly heterogeneous across countries.

At the panel level, energy consumption emerges as the most dominant and persistent driver of greenhouse gas (GHG) emissions in both the short and long run. This result reflects the region's continued dependence on energy systems and is consistent with earlier empirical evidence (Joo & Shawl, 2023; Djellouli *et al*., 2022) [6, 9]. Although renewable energy consumption contributes to mitigating emissions, its current scale appears insufficient to fully offset the environmental pressures generated by rising energy demand. Most importantly, the long-run PMG estimates reveal a positive and statistically significant relationship between FDI and GHG emissions, providing strong empirical support for the Pollution Haven Hypothesis in South Asia. This finding aligns with Murthy and Gambhir (2018) and Temurshoev (2006) [14, 23], who argue that countries with relatively lax environmental regulations tend to attract pollution-intensive foreign investments over time. In contrast, the short-run FDI coefficients are statistically insignificant, suggesting that pollution-haven effects do not materialize immediately but instead emerge gradually as foreign-funded activities expand and mature.

Country-specific short-run results further underscore the heterogeneous nature of PHH dynamics across South Asia. The error correction terms are negative and statistically significant for Bangladesh, India, Pakistan, and Sri Lanka, confirming convergence toward a common long-run equilibrium, albeit at different speeds. India exhibits the fastest adjustment process, reflecting greater economic flexibility, while Sri Lanka demonstrates the slowest adjustment, indicative of structural rigidities.

With respect to the PHH at the country level, Bangladesh, India, and Pakistan show no statistically significant short-run relationship between FDI and GHG emissions, reinforcing the interpretation that pollution-haven effects are primarily a long-run phenomenon. In contrast, Sri Lanka displays a negative and statistically significant short-run association between FDI and emissions, contradicting the PHH and instead supporting the pollution-halo hypothesis. This finding suggests that foreign investment in Sri Lanka may be oriented toward cleaner production processes or subject to stronger environmental oversight. Overall, the results confirm the existence of the Pollution Haven Hypothesis in South Asia in the long run, while highlighting the importance of country-specific institutional quality, environmental regulation, and energy structures in shaping short-run environmental outcomes.

Given these insights, the study outlines several policy recommendations. South Asian governments should improve and enforce environmental regulations for foreign investment to mitigate the long-term pollution-haven effects identified. Implementing stricter environmental standards, enforcing compliance mechanisms, and mandating environmental impact assessments for foreign-funded projects are essential steps toward aligning FDI with sustainable development objectives. Emphasis needs to be placed on enhancing renewable energy sources and energy efficiency while promoting green FDI through various incentives, technology transfer agreements, and public private partnerships can help redirect foreign capital toward environmentally sustainable sectors.

Furthermore, the need for tailored country-specific responses is critical; Bangladesh and Pakistan should deter pollution-heavy investments while promoting clean industrial development. India is encouraged to accelerate renewable energy integration and enhance environmental compliance among foreign investors, and Sri Lanka should build on its short-run pollution-halo effects by further strengthening environmental governance and attracting responsible FDI.

In conclusion, this study provides compelling evidence that the environmental impact of foreign direct investment in South Asia is fundamentally a long-run phenomenon consistent with the Pollution Haven Hypothesis. Sustainable economic growth in the region requires an integrated policy framework that combines clean energy transition, strong environmental regulation, and strategically guided foreign investment.

References

1. Abidin İSZ, Haseeb M, Azam M, Islam R. Foreign Direct Investment, Financial Development, InternationalTrade and Energy Consumption: Panel Data Evidence fromSelected ASEAN Countries. International Journal of Energy Economics and Policy,2015:5(3):841–50.
2. Acaravci A, Ozturk I. On the Relationship between Energy Consumption, CO2 Emissions and Economic Growth in Europe. Energy,2010:35(12):5412–20.
3. Banday U, Aneja R. Energy Consumption, Economic Growth and CO2 Emissions: Evidence from G7 Countries,2019:16:20–39.
4. Bhat V, Tantri ML. Pollution Haven Hypothesis and the Bilateral Trade Between India and China. Journal of Current Chinese Affairs,2023:18681026231188450.
5. Chu JF, Sek SK. Investigating the Relationship between Inflation and Growth: Evidence from Panel ARDL Models,2014:943–48.
6. Djellouli N, Abdelli L, Elheddad M, Ahmed R, Mahmood H. The Effects of Non-Renewable Energy, Renewable Energy, Economic Growth, and Foreign Direct Investment on the Sustainability of African Countries. Renewable Energy,2022:183:676–86.
7. Garidzirai R, Muzindutsi P-F. A Panel ARDL Analsis of the Productivity of Key Economic Sectors Contributing to Local Economic Growth in an Emerging Country. Studia Universitatis Babes-Bolyai Oeconomica,2020:65(1):39–53.
8. Irfan M, Ojha RK. Foreign Direct Investment Inflows and Energy Diversification in Emerging Seven Economies: Evidence from a Panel Data Analysis, 2022.
9. Joo BA, Shawl S. Understanding the Relationship Between Foreign Direct Investment and Economic

Growth in BRICS: Panel ARDL Approach. Vikalpa,2023:48(2):100–113.
10. Kasperowicz R. Economic Growth and Energy Consumption in 12 European Countries: A Panel Data Approach. Journal Of International Studies,2014:7(3):112–22.
11. Lee CC, Chang CP. Energy Consumption and Economic Growth in Asian Economies: A More Comprehensive Analysis Using Panel Data. Resource and Energy Economics,2008:30(1):50–65.
12. Li W, Qiao Y, Li X, Wang Y. Energy Consumption, Pollution Haven Hypothesis, and Environmental Kuznets Curve: Examining the Environment–Economy Link in Belt and Road Initiative Countries. Energy,2022:239:122559.
13. Mehmood U. Renewable energy and foreign direct investment: Does the governance matter for CO_2 emissions? Application of CS-ARDL. Environmental Science and Pollution Research,2022:29(13):19816–19822.
14. Murthy KV, Gambhir S. Analyzing Environmental Kuznets Curve and Pollution Haven Hypothesis in India in the Context of Domestic and Global Policy Change. Australasian Accounting, Business and Finance Journal,2018:12(2):134–56.
15. Nazah N, Duasa J, Arifin MI. Fertility and Female Labor Force Participation in Asian Countries; Panel ARDL Approach. Jurnal Ekonomi Studi Pembangunan,2021:22(2):272–88.
16. Ozturk I, Farooq S, Majeed MT, Skare M. An Empirical Investigation of Financial Development and Ecological Footprint in South Asia: Bridging the EKC and Pollution Haven Hypotheses. Geoscience Frontiers,2024:15(4):101588.
17. Pesaran MH, Shin Y, Smith RP. Pooled mean group estimation of dynamic heterogeneous panels. Journal of the American Statistical Association,1999:94(446):621–634.
18. Polloni-Silva E, Ferraz D, Camioto FdC, Rebelatto DAdN, Moralles HF. Environmental Kuznets Curve and the Pollution-Halo/Haven Hypotheses: An Investigation in Brazilian Municipalities. Sustainability,2021:13(8):4114.
19. Radmehr R, Shayanmehr S, Ali EB, Ofori EK, Jasińska E, Jasiński M. Exploring the nexus of renewable energy, ecological footprint, and economic growth through globalization and human capital in G7 economics. Sustainability,2022:14(19):19.
20. Sarkodie SA, Strezov V. Effect of Foreign Direct Investments, Economic Development and Energy Consumption on Greenhouse Gas Emissions in Developing Countries. Science of The Total Environment,2019:646:862–71.
21. Tang CF, Tan BW. The impact of energy consumption, income and foreign direct investment on carbon dioxide emissions in Vietnam. Energy,2015:79:447–454.
22. Taşkın D, Vardar G, Okan B. Does Renewable Energy Promote Green Economic Growth in OECD Countries? Sustainability Accounting, Management and Policy Journal,2020:11(4):771–98.
23. Temurshoev U. Pollution Haven Hypothesis or Factor Endowment Hypothesis: Theory and Empirical Examination for the US and China, 2006.
24. Tran TN, Nguyen TT, nguyen vc, vu tth. Energy consumption, economic growth and trade balance in east asia: a panel data approach. International Journal of Energy Economics and Policy,2020:10(4):443–49.
25. Dagar V, Ahmed F, Waheed F, Bojnec Š, Khan MK, Shaikh S, *et al*. Testing the Pollution Haven Hypothesis with the Role of Foreign Direct Investments and Total Energy Consumption. Energies, 2022, 15(11).
26. Zardoub A. Exploring the Links between Financial Flows and Economic Growth: A Panel ARDL Approach. PSU Research Review,2021:7(2):90–104.
27. Zhang C, Zhou X. Does Foreign Direct Investment Lead to Lower CO2 Emissions? Evidence from a Regional Analysis in China. Renewable and Sustainable Energy Reviews,2016:58:943–51.
28. Zhu H, Duan L, Guo Y, Yu K. The Effects of FDI, Economic Growth and Energy Consumption on Carbon Emissions in ASEAN-5: Evidence from Panel Quantile Regression. Economic Modelling,2016:58:237–48.