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Balancing Growth and Green Goals: Unravelling Greenhouse Gas Drivers in SAARC Economies

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ABSTRACT

The present study explores the key drivers of Greenhouse Gas Emissions (GHG) in SAARC region. For this purpose, the study used panel data of thirty-four years from 1990 to 2024 and employed the Pooled Mean Group (PMG) ARDL method. Several factors are responsible for global warming and climate change, but the present study incorporated some major factors such as industrialization, foreign direct investment, economic growth, renewable energy, and non-renewable energy etc. Findings revealed that industrialization, FDI, GDP, and fossil fuel-based energy contributed positively while GDP square and renewable energy contributed negatively towards Greenhouse Gas Emissions (GHG) in SAARC economies. The analysis also validated the Environmental Kuznets Curve (EKC) hypothesis for these countries. The study concluded with the policy suggestion to encourage the renewable energy projects like hydro, wind, solar, biomass, etc. to ensure a clean, and eco-friendly environment for the safety of humans, animals, plants, and the planet that protects nature, reduces pollution, and promotes sustainability.

1. Introduction

In 21st century, every country faced the problem of climate change. In recent years, environmental sustainability and climate change have occurred as some of the highly critical economic challenges. Climate change and global warming are mostly initiated by greenhouse gas emissions. On the other hand, carbon dioxide emissions have gotten a lot of attention in environmental literature as the principal component of greenhouse gases. CO_2 and GHG emissions are considered responsible for climate change and environmental degradation. CO_2 emissions are discharged into the atmosphere through the oxidation of fossil fuels and the decomposition of wood and other organic materials. Under all these circumstances, CO_2 emission is an indistinguishable and fragrance-free gas, it is eliminated from plants to atmosphere which extract CO_2 to build their tissues and to oceans in which CO_2 dissolves. Forest dismantling has become a foremost cause of increment in CO_2 emissions in more recent times. According to the International Energy Agency (IEA), rising fossil fuel consumption has caused CO_2 emissions and GHG emissions to rise, necessitating a quick transition to cut CO_2 and GHG emissions and meet sustainable goals (IEA, 2021). Furthermore, the United Nations (UN) has established Sustainable Development Goals (SDGs), which emphasize the necessity for clean economic energy, technical innovation, sustainable consumption, production, and economic growth as instantly required ways to combat climate change by 2030 (United Nation, 2015).

The primary objective of developing nations is to improve quality of life which can be achieved by accelerating economic growth. Most nations must face the combined difficulties of economic growth and as well as environmental quality to attain the Sustainable Development Goals agenda (Govindaraju, & Tang, 2013). The linkage between economic challenges and environmental quality has become a highly debated topic among scholars, researchers, and environmentalists. Policymakers and scholars are committed to reducing pollution emissions without harming economic performance, as economic activities and carbon emissions are closely linked. As a result, limiting carbon emissions and greenhouse gas emissions has been a key concern for various countries, and the advancement of green technology innovation has now become a key component in promoting global economic change.

According to the empirical reviews of literature, there are many factors that contribute to the GHG and CO_2 emissions in various countries. These factors are economic growth, energy consumption, foreign direct investment, population, urbanization, technological innovations and foreign trade. A lot of studies have been done to find out the key drivers of CO_2 and GHG emissions. The South Asian region comprises various countries, incorporating Pakistan, Afghanistan, India, Bangladesh, Maldives, Bhutan, Sri Lanka, and Nepal. In recent years, problem of environmental deterioration in South Asian countries has gotten worse. This results mainly from large-scale industrialization, and increasing use of non-renewable energy including fossil flues, coal, oil etc. and development of large cities or urbanization. So, this research is therefore undertaken to observe the factors of Greenhouse Gas Emissions (GHG) in the South Asian region. A very limited number of studies on this topic are conducted following the review of literature, especially in South Asian Region.

Greenhouse gas discharges have emerged as an insistent global issue because of their substantial contribution to climate change and environmental deterioration. South Asia, which lodges nearly one-fourth of the global population and is suffering rapid economic extension, industrialization, and urbanization, has recorded a sharp increase in GHG emissions over the past few decades. Although the region's overall contribution to global emissions remains lower than that of developed economies, it faces severe climate-related challenges such as rising temperatures, unpredictable rainfall patterns, frequent flooding, and reduced agricultural output. Despite these trends, there is still insufficient knowledge about the economic, demographic, and structural factors influencing GHG emissions within South Asia. Variables including population growth, energy utilization, trade liberalization, industrial development, and technological advancement may exert diverse and interconnected effects on emission levels across countries like Pakistan, India, Bangladesh, Sri Lanka and Nepal. The lack of region-specific empirical research creates obstacles for policymakers in developing effective and evidence-based strategies for emission reduction. Consequently, this study seeks to explore the principal drivers of GHG emissions in South Asia by analyzing the influence of economic, demographic, and energy-related factors over time. Understanding these relationships will help design policies that promote sustainable growth while minimizing environmental harm.

2. Review of Literature

Obobisa, et al., (2022), analyzed the long-term impacts of eco-innovation, institutional performance, sustainable energy, economic growth, and fossil fuel consumption on CO_2 emissions. They used panel data of twenty-five African countries from years 2000 to 2018 and employed second-generation panel techniques of Augmented Mean Group (AMG) and Common Correlated Effects Mean Group (CCEMG). Their findings showed negative impact of green technology innovation and renewable energy use on CO_2 emissions, while economic growth, institutional quality and fossil fuel energy use showed positive impact on CO_2 emissions. Their study suggested to promote the investment in renewable energy projects in African countries.

Ahmad et al. (2022) explored the influence of financial development, institutional quality, and human capital on the environmental footprint of emerging economies. They utilized panel data covering seventeen developing nations over the period 1984–2017 and employed both short- and long-term dynamics, the Cross-Sectional Autoregressive Distributed Lag (CS-ARDL) technique. Their findings indicated that financial development tends to deteriorate environmental quality by increasing the ecological footprint while human capital and institutional quality were found to alleviate environmental pressure. Moreover, the results suggested that financial development can foster environmental sustainability through the mediation of human capital, while the adverse environmental impact of financial development diminishes if there is active contribution of strong institutional quality.

Khan et al. (2022) worked on the role of institutional quality in influencing the link between foreign direct investment (FDI) and carbon emissions reduction using panel data from 107 developing countries and 39 Belt and Road Initiative (BRI) countries over the period 2002–2019.

The study incorporated static and dynamic panel models by using variables such as institutional quality, CO_2 emissions, FDI, trade, economic growth, energy consumption, and urbanization. The results indicated that governance factors are essential for attracting FDI inflows. Institutional quality positively affected FDI, while energy consumption exerted a negative impact. Environmental Kuznets Curve (EKC) was also validated. Additionally, FDI and trade were found to increase emissions globally and in developing countries, whereas BRI nations experienced emission reductions. Overall, institutional quality was shown to moderate the effect of FDI on carbon emission reduction across all models.

Adeleye, et al., (2021), examined the complex connection between economic growth, energy-consumption and emissions in South Asia. For this purpose, the study used CO2 emissions/capita, GDP/capita, renewable energy and energy use/capita from seven South Asian countries for the time duration 1990 to 2019. They employed Panel Corrected Standard Errors (PCSE), Feasible Generalized Least Squares (FGLS), Bootstrapping Ordinary Least Squares (BOLS) techniques, etc. Their findings showed that economic growth and non-renewable energy increase pollution, while renewable energy helps reduce it and as economies grow, they further strengthen the positive impact of renewable energy and weaken the harmful effects of non-renewable energy.

Alharthi et al. (2021) employed novel quantile estimation techniques to examine the determinants of CO_2 emissions in MENA countries by using the Environmental Kuznets Curve (EKC) hypothesis. They sued panel data for the period from 1990 to 2015 and incorporated variables such as CO_2 emissions, real income, renewable and nonrenewable energy consumption, and urbanization. The simulation findings indicated that the adoption of renewable energy significantly reduces emissions, with its impact becoming more pronounced at higher quantile levels. Moreover, the use of non-renewable energy increases CO_2 emissions, and this effect diminishes at higher quantile levels. The empirical results for MENA countries also validated the Environmental Kuznets Curve (EKC) hypothesis.

Yin, et al., (2021), examined the unequal socio-economic elements that contribute to CO_2 emissions for China by using annual data from 1980 to 2019 and non-linear ARDL technique. The study used data of different variables, CO_2, GDP, energy consumption, year of schooling, trade, foreign direct investment, and urbanization. The findings revealed that in China, positive economic development is the primary generator of CO_2 emissions, whereas negative economic growth offsets CO_2 emissions. In the long run, both positive and negative changes in energy consumption showed negative effects on CO_2 emissions, while a negative shock has a moderate impact on CO_2 emissions compared to a positive energy shock. Positive years of learning, as well as shocks, have proved to be advantageous in China's long-term fight against CO_2 emissions.

3. Theoretical Framework

The relationship between various measures of income/capita and environmental degradation is commonly explained through the Environmental Kuznets Curve (EKC) hypothesis, originally proposed by Gene M. Grossman and Alan B. Krueger in their influential study. EKC shows that the reduced form relationship between income/capita and several environmental indicators does not exhibit a continuous decline, instead, environmental quality tends to deteriorate during the initial stages of economic development and improves after reaching a certain income threshold. This pattern reflects the inverted U-shaped form of the Environmental Kuznets Curve (EKC), as illustrated in Figure 1.

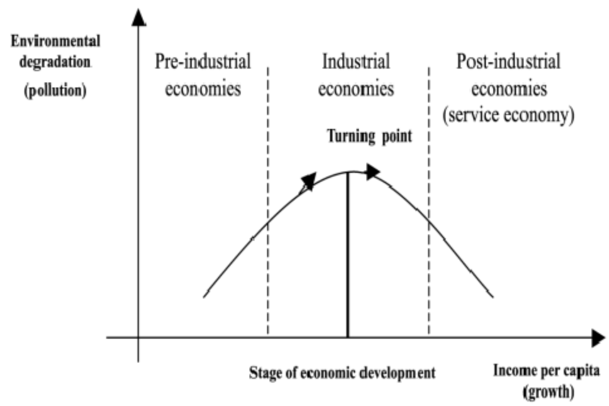

Figure 1: Environmental Kuznets Curve (EKC) Hypothesis

4. Research Methodology

4.1 Data

This study is based on secondary data sources and utilizes panel data of South Asian countries such as, Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan and Sri Lanka from years 1990 to 2024. The data is collected from WDI, the descriptions of data and their sources are given in table 1 below.

Table 1: Descriptions of Variables

Sr. #	Variable	Description	Measurement Unit	Sources
1	**GHG**	Greenhouse Gas Emissions	Total, Per Capita	WDI
2	**IND**	Industrialization	Value Added % of GDP	WDI
3	**FDI**	Foreign Direct Investment	Inflow, % of GDP	WDI
4	**GDP**	Gross Domestic Product	Annual Growth	WDI
5	**GDP^2**	Square of Gross Domestic Product	Annual Growth	Excel
6	**RE**	Renewable Energy	% of Final Consumptions	WDI
7	**NRE**	Non-Renewable Energy	% of Fossil Fuels Consumptions	WDI

Sources: World Development Indicators

4.2 Model

This study is undertaken to analyze the key drivers of greenhouse gas emissions in case of SAARC economies. For this purpose, the study formulates the following mathematical and econometric models.

$$\boldsymbol{GHG} = f\,(IND, FDI, GDP, GDP^2, RE, NRE)\ \ldots\ \mathbf{(1)}$$

$$GHG_{it} = \beta_0 + \beta_1 IND_{it} + \beta_2 FDI_{it} + \beta_3 GDP_{it} + \beta_4 GDP^2_{it} + \beta_5 RE_{it} + \beta_6 NRE_{it} + €_t \text{ .... } (2)$$

The model is converted in logarithm form.
β_0 = Intercept
All other β's = Elastic coefficients of each variable
€ = Error term

4.3 Methods of Estimation

The most popular statistical models for examining the short run and long run connection between variables are Autoregressive distributed lag (ARDL), and PMG-ARDL Approach is an extension of ARDL and is mostly used in panel data analysis for long and short run dynamics. For this purpose, the usual process is to perform a unit test first.

4.3.1 Unit Root Test

Due to the assumption of data stationarity in many econometric models, unit root analysis is crucial. Stationarity is a key component of time series research as many statistical models and methodologies rely on stationary data to produce precise estimates and projections. There are different tests of unit root. ADF and PP tests are used in this study to check for unit root. The hypothesis of these tests are:
H_0 = Series has a Unit Root
H_1 = Series does not Unit Root

4.3.2 Cross Sectional Dependency and Pooled Mean Group ARDL (PMG-ARDL) Methods

Pesaran Cross Sectional Dependency (CSD) test and the Pesaran Scaled LM test are used to trace the presence of CSD in a panel of South Asian countries. Due to the existence of CSD and presence of integration of mixed order, the second-generation PMG-ARDL approach is used to estimate the long-run panel cointegration connection among the chosen variables in the model. This strategy consistently and effectively resolves the problems of heterogeneity, autocorrelation, and endogeneity (Narayan, 2005; Alam, et al., 2025). Additionally, even with a small sample size, the PMG-ARDL estimator has proven to be effective. Additionally, the long run values are compatible with the usual F-test and t-distribution tests (Pesaran, et al., 1999).

$$\Delta GHG_{it} = b_i\left(GHG_{i,t-1} - \Delta_i n_{i,t-1}\right) + \sum_{j=0}^{y-1} \sigma_{ij}\, \Delta n_{i,t-1} + \sum_{j=0}^{x-1} \varepsilon_{ij}\, \Delta n_{i,t-1} + \Delta_i + \mu_{it} \text{ ... } (\mathbf{3})$$

The current study consists of one model, which is greenhouse gas. In the equation above, the dependent variable is greenhouse gas in equation. Further, ($GHG_{i,\,t-1} - \sigma_i n_{i,\,t-1}$) represent the long run deviation and "b_i" point out the error correction term which is normally negative and statistically significant and shows the speed of adjustment. Additionally, the model's short-run and long-run coefficients are represented by the vectors ε_{ij} and σ_{ij}. In the last, μ_{it} represents the important factors such as, IND, FDI, GDP, GDP^2, RE, and NRE which affects dependent variables

GHG.

4.3.3 General Equation of PMG-ARDL Estimator

The Pooled Mean Group (PMG) ARDL model integrates both short-run and long-run equilibrium relationships. It permits heterogeneity in short-run coefficients across cross-sectional units while maintaining a common long-run relationship among them. The general form of PMG-ARDL model, representing both short-run and long-run equations, is presented separately for each model below.

4.3.4 Short Run Equation of PMG-ARDL Estimator

$$\Delta(GHG)_{it} = \alpha + \beta_1(GHG)_{it-1} + \beta_2(IND)_{it-1} + \beta_3(FDI)_{it-1} + \beta_4(GDP)_{it-1} + \beta_5(GDP^2)_{it-1} + \beta_6(REN)_{it-1} + \beta_7(NREN)_{it-1} + \sum_{i=1}^{a_1} \delta_1\Delta(GHG)_{it-1} + \sum_{i=1}^{a_2} \delta_2\Delta(IND)_{it-1} + \sum_{i=1}^{a_3} \delta_3\Delta(FDI)_{it-1} + \sum_{i=0}^{\alpha_4} \delta_4\Delta(GDP)_{it-1} + \sum_{i=0}^{\alpha_5} \delta_5\Delta(GDP^2)_{it-1} + \sum_{i=0}^{\alpha_6} \delta_6\Delta(REN)_{it-1} + \sum_{i=0}^{\alpha_7} \delta_7\Delta(NREN)_{it-1} + \varepsilon_{it} \ldots\ldots\ldots (6.1)$$

4.3.5 Long Run Equation of PMG-ARDL Estimator

$$\Delta(GHG)_{it} = \alpha + \sum_{i=1}^{a_1} \eta_1(GHG)_{it-i} + \sum_{i=0}^{a_2} \eta_2(IND)_{it-i} + \sum_{i=1}^{a_3} \eta_3(FDI)_{it-i} + \sum_{i=1}^{a_4} \eta_4(GDP)_{it-i} + \sum_{i=1}^{a_5} \eta_5(GDP^2)_{it-i} + \sum_{i=1}^{a_6} \eta_6(REN)_{it-i} + \sum_{i=1}^{a_7} \eta_7(NREN)_{it-i} + \epsilon_{it} \ldots\ldots\ldots (6.2)$$

4.3.6 Error Correction Method (ECM) Equation

Both short-term and long-term associations between variables may be estimated using the Panel ARDL model. The model can be converted into an Error Correction Model (ECM) to represent the long-term equilibrium connection. In the short run, the general equation of Panel ARDL model can be written in the form:

$$\Delta(GHG)_{it} = a + \sum_{i=1}^{a_1} \lambda_1\Delta(GHG)_{it-i} + \sum_{i=1}^{a_2} \lambda_2\Delta(IND)_{it-i} + \sum_{i=1}^{a_3} \lambda_3\Delta(FDI)_{it-i} + \sum_{i=1}^{a_4} \lambda_4\Delta(GDP)_{it-i}$$

$$+\sum_{i=1}^{a_5}\lambda_5\Delta(GDP^2)_{it-i}+\sum_{i=1}^{a_6}\lambda_6\Delta(REN)_{it-i}+\sum_{i=1}^{a_7}\lambda_7\Delta(NREN)_{it-i}+\ \omega ECM_{it-1}$$
$$+\ \varepsilon_{it}\ \ldots\ldots..(6.3)$$

4.3.7 Panel Long Run Co-Integration

Kao Residual Co-integration test is used to analyze the long-run co-integration association among the set of variables included in the model after confirming the presence of a long-run panel co-integration relationship. This test is very useful for examining the long run co-integration among variables and it is similar to Pedroni Residuals Co-integration Test.

5. Empirical Results and Analysis

5.1 Descriptive Statistics

It is necessary to disclose the dataset's descriptive nature prior to starting the actual examination. The descriptive statistics of key variables used in this study are given in the table below.

Table 2: Descriptive Statistics

	GHG	*IND*	*FDI*	*GDP*	*GDP²*	*REN*	*NREN*
Mean:	*0.22747*	*1.34847*	*-0.50594*	*0.74953*	*1.47785*	*1.52993*	*0.19541*
Median:	*0.23209*	*1.38523*	*-0.15756*	*0.74683*	*1.49147*	*1.68078*	*1.03607*
Maximum:	*0.78127*	*1.61932*	*1.22488*	*2.14362*	*4.04459*	*1.98181*	*1.87958*
Minimum:	*-0.22057*	*0.90624*	*-14.6511*	*-0.92030*	*-2.79942*	*-0.09691*	*-5.87218*
Std. Dev.:	*0.21196*	*0.15917*	*1.90680*	*0.37947*	*0.77352*	*0.51896*	*1.71444*
Skewness:	*0.14557*	*-0.77016*	*-4.98791*	*0.14207*	*-0.58179*	*-1.79679*	*-0.59948*
Kurtosis	*3.10962*	*2.88864*	*31.1477*	*7.21547*	*9.49801*	*5.14511*	*2.16647*
JB Stat:	*1.12912*	*27.8253*	*10404.4*	*208.261*	*508.412*	*204.346*	*24.8769*
Prob.:	*0.56861*	*0.00001*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00004*
Sum:	*63.6933*	*377.571*	*-141.663*	*209.868*	*413.798*	*428.380*	*54.7169*
Sum. Sq. Dev.:	*12.5357*	*7.06865*	*1014.41*	*40.1768*	*166.938*	*75.1404*	*820.068*
Obs.:	*280*	*280*	*280*	*280*	*280*	*280*	*280*

The descriptive analysis shows that almost the mean and median values of all variables are similar, showing evenly and balanced distributions. FDI shows negative value and fluctuations like extreme left-skewness and strongly high kurtosis showing due to the existence of outliers in the pattern of foreign investment. In comparison, renewable energy consumption use averages greater than non-renewable energy use, though left-skewness and strongly high kurtosis showing unbalanced adoption across countries.

5.2 Diagnostic Tests

Unit root test is used to ascertain the stationarity of the parameters prior to performing cointegration. The results are given separately for intercept and trend & intercept in table 3 below.

Table 3: Results of Panel Unit Root Tests

Variables	ADF - Fisher Chi-square Test				PP - Fisher Chi-square Test				Results
	At Level		At 1st Difference		At Level		At 1st Difference		
	Intercept	Trend & Intercept	Intercept	Trend & Intercept	Intercept	Trend & Intercept	Intercept	Trend & Intercept	
GHG:	*14.2299 (0.5816)*	*18.8943 (0.2742)*	*83.2427* (0.0000)*	*63.8119* (0.0000)*	*12.6204 (0.7003)*	*21.665 (0.1543)*	*158.317* (0.0000)*	*326.516* (0.0000)*	***I(1)***
IND:	*11.8500 (0.7542)*	*19.6743 (0.2352)*	*105.556* (0.0000)*	*91.4374* (0.0000)*	*10.6489 (0.8306)*	*17.8836 (0.3308)*	*165.968* (0.0000)*	*302.002* (0.0000)*	***I(1)***
FDI:	*69.8203* (0.0000)*	*42.4538* (0.0003)*	*150.169* (0.0000)*	*136.540* (0.0000)*	*56.6780* (0.0000)*	*33.8836* (0.0056)*	*201.751* (0.0000)*	*300.033* (0.0000)*	***I(0)***
GDP:	*96.6101* (0.0000)*	*78.3124* (0.0000)*	*191.022* (0.0000)*	*159.589* (0.0000)*	*124.668* (0.0000)*	*124.578* (0.0000)*	*222.893* (0.0000)*	*150.851* (0.0000)*	***I(0)***
GDP^2:	*86.1861* (0.0000)*	*69.5380* (0.0000)*	*188.712* (0.0000)*	*162.510* (0.0000)*	*129.638* (0.0000)*	*125.977* (0.0000)*	*223.972* (0.0000)*	*166.668* (0.0000)*	***I(0)***
REN:	*3.87552 (0.9991)*	*12.1560 (0.7332)*	*81.4244* (0.0000)*	*55.6497* (0.0000)*	*3.50695 (0.9995)*	*15.8177 (0.4658)*	*178.711* (0.0000)*	*165.336* (0.0000)*	***I(1)***
NREN:	*27.8455** (0.0330)*	*48.84732** (0.0195)*	*56.3906* (0.0000)*	*51.3099* (0.0000)*	*25.7494** (0.0477)*	*54.4472* (0.0054)*	*103.055* (0.0000)*	*350.322* (0.0000)*	***I(0)***

Significance Level, *1%, **5% and ***10%

The test statistics are compared with critical values at different levels i-e 1%, 5%, and 10% to establish whether to reject the null hypothesis. The results illustrate that FDI, GDP, GDP^2 and NREN are stationary at level and intercept, because their values are less than 5% level of significance and these variables are I(0). GHG, IND and REN are stationary at first difference and intercept, because their values are less than 1%, 5%, and 10% level of significance and these variables are I(1). So, the null hypothesis is rejected, and it is concluded that time series does not have a unit root meaning that these variables are stationary. For this reason, the data is perfect for the Panel ARDL estimator and co-integration.

Diagnostic tests are statistical techniques and tools used to check the validity of a model and ensure that the results are accurate. Different tests are used to identify the problem of Multicollinearity, Heteroscedasticity, Autocorrelation or Serial Correlation. Table 4 below shows the results of Pair – Wise Correlation Matrix used to diagnose the problem of Multicollinearity..

Table 4: The Results of Pair – Wise Correlation Matrix

Pair – Wise Correlation Matrix							
Variables	**GHG**	**IND**	**FDI**	**GDP**	**GDP^2**	**REN**	**NREN**
GHG:	**1.000000**						
IND:	-0.135782	**1.000000**					
FDI:	0.357902	-0.250902	**1.000000**				
GDP:	-0.121220	0.123503	-0.475599	**1.000000**			
GDP^2:	-0.063174	0.138096	-0.449456	0.822628	**1.000000**		
REN:	-0.241174	0.577332	-0.173606	-0.148432	-0.184359	**1.000000**	
NREN:	-0.129935	0.170555	0.103504	-0.162453	-0.122579	0.466049	**1.000000**

Higher value indicates the higher correlation among variables. The range of coefficient of correlation lies from +1 (perfect positive) to -1 (perfect negative). The values of all variables are less than 0.9, so the overall results demonstrate that the estimated model is free from the issue of multicollinearity.

Table 5 below shows the results of Serial Correlation LM test used to diagnose the problem of autocorrelation, Breusch-Pagan-Godfrey used to diagnose the problem of Heteroskedasticity and Ramsey RESET test used to check for the specification errors.

Table 5: The Results of Diagnostic Tests Analysis

Test	***Interpretations***				***Conclusion***
Serial Correlation LM Test: *(Autocorrelation)*	***F-Stat:***	*0.41393*	***Prob.(2,269)***	*0.6615*	*Accepted (H_1) of No Autocorrelation*
	Obs*R^2:	*0.85600*	***Prob.Chi^2.***	*0.6518*	
Breusch-Pagan-Godfrey *(Heteroskedasticity Test)*	***F-Stat:***	*1.38596*	***Prob.(7,271)***	*0.2112*	*Accepted (H_1) of No Heteroskedasticity*
	Obs*R^2:	*9.64296*	***Prob.Chi^2.***	*0.2097*	
		Value	***df***	***Prob.***	

Ramsey RESET Test *(Specifications Errors)*	***t-Stat:***	*0.81749*	*270*	*0.3502*	*The Model is Well Specified*
	f-Stat:	*0.93825*	*(1,270)*	*0.3502*	
	Liklehood Ratio:	*0.08459*	*1*	*0.4775*	

The findings of diagnostic test show that PMG-ARDL model is significant and suitable for analysis. The high probability value (>0.05) is driven from the Serial Correlation LM test, and it shows that there is no autocorrelation among residuals. On the other hand, insignificant p-value results in Breusch–Pagan–Godfrey test suggesting no evidence of heteroskedasticity. Moreover, insignificant p-value from the Ramsey RESET implies that model is properly specified and there is no issue of functional form.

The cross-sectional dependence happens when the errors in the model are correlated across different units in the same period. The existence of CSD in panel data models will be central to wrong estimates, inefficient standard errors, and misleading inferences. Therefore, in the analysis of panel data, examining the dependence of cross-sectional is very important. The outcomes of the cross-sectional dependence test are shown in table 6 below.

Table 6: The Results of Kao Residual Co-Integration Test

Kao Residual Co-Integration Test **Series:** GHG, IND, FDI, GDP, GDP^2, REN, NREN		
ADF	**t-Statistic:**	**Prob.**
	-2.183039	0.0145
Residual Variance:	0.000939	
HAC Variance:	0.000921	

The results of CSD test of both models are provided in the table above. The results imply that P-values of Breusch-Pagan LM Test, Pesaran Scaled LM and Pesaran CD are greater than 0.05 or 5% and 10% level of significance; it indicates the acceptance of null hypothesis and concludes that there is no cross-sectional dependence meaning that residuals are independent.

5.3 Long Run Results of Co-Integration of PMG-ARDL Method

In the analysis of panel data, the main purpose to test long-run cointegration is to check whether the different valuables are linked through a stable equilibrium relationship across different SAARC countries used for this study.

Table 7 below shows the results of long run coefficients of co-integration.**Table 7:** The Long Run Results of Panel PMG-ARDL

Long Run Co-integration
Dependent Variable: *Log of Greenhouse Gas Emissions*

Variables	*Coefficient*	*Std. Error*	*t-Stat*	*Prob.*
IND:	*0.489337*	*0.112780*	*4.338867*	*0.0000**
FDI:	*0.297808*	*0.130661*	*2.180482*	*0.0303***
GDP:	*0.398294*	*0.980640*	*2.908899*	*0.0176***
GDP^2:	*-0.223107*	*0.511029*	*-3.046854*	*0.0091**
REN:	*-0.692911*	*0.079415*	*-8.725242*	*0.0000**
NREN:	*0.296040*	*0.037349*	*7.926347*	*0.0000**

Significance Level, *1%, **5% and ***10%

Findings from the long-run PMG-ARDL represent that industrial development (IND), foreign direct investment (FDI), GDP, and non-renewable energy consumption (NREN) are the main factors to greenhouse gas emissions in the long run, as per their positive and significant values of co-efficient. A 1% raise in industrial output and FDI raises emissions by 0.49% and 0.29% respectively, whereas GDP growth share is 0.39% in emissions showing the scale effect of economic expansion.

The existence of an Environmental Kuznets Curve (EKC) results due to the negative and significant coefficient of GDP^2. It explains that there will be diseconomies of scale as after a certain income level economic growth helps to reduce emissions. Emission is reduced by 0.69% due to the negative and highly significant impact and highlights its vital role in lowering environmental ruin. In conclusion, economic growth first causes environmental degradation but with the growth of economy more use of renewable energy becomes very important in reducing emissions.

5.4 Short Run Results of Error Correction Method

The objective of ECM model in the analysis of panel data is to capture the short-term adjustments among variables and evaluate the extent that how rapidly the system restores to long-run equilibrium after a shock. It distinguishes the short-run effects from long-run relationships and measures the extent of convergence back to equilibrium. Table 8 below shows the results of short run coefficients of ECM.

Table 8: The Short Run Results of Error Correction Method (ECM)

Error Correction Model				
Dependent Variable: *Log of Greenhouse Gas Emissions*				
Variables	*Coefficient*	*Std. Error*	*t-Stat*	*Prob.*
COINTEQ01:	*-0.690426*	*0.340590*	*-2.920342*	*0.0077**
D(IND):	*0.166821*	*0.042603*	*1.568453*	*0.0483***
D(FDI):	*0.137054*	*0.012881*	*1.670803*	*0.0568****
D(GDP):	*0.148495*	*0.148456*	*1.956471*	*0.0618****
D(GDP^2):	*-0.071264*	*0.228624*	*2.011913*	*0.0551****
D(REN):	*-0.218467*	*0.103088*	*-5.262759*	*0.0000**
D(NREN):	*0.199062*	*0.074424*	*2.268216*	*0.0088**

Significance Level, *1%, **5% and ***10%

The short-run ECM results show that the error correction term is negative and significant, indicating that about 69% of short-term disequilibrium is corrected each period, reflecting rapid adjustment toward long-run stability. Industrial development, FDI, GDP, and non-renewable energy use all have positive and significant effects on greenhouse gas emissions, while GDP^2 is negative and significant, confirming a short-run EKC pattern. Renewable energy has a strong negative impact, showing its immediate role in reducing emissions. Overall, the short-run results align with the long-run findings—economic growth initially raises emissions, but renewable energy helps mitigate them. The short-run results mirror the long-run findings, revealing that economic and industrial growth first elevates emissions, but renewable energy contributes to their reduction.

6. Conclusions and Policy Implications

The focus of present study is to find out the key drivers of Greenhouse Gas (GHG) Emissions in SAARC region by using panel data of 34 years from 1990 to 2024. The theory of Environmental Kuznets Curve (EKC) is used which states that there is a negative relationship between Greenhouse Gas (GHG) Emissions and growth of the economy. The findings of ADF test, PP test, and CSD test support that the appropriate technique to use for this study is PMG-ARDL. The empirical findings of PMG ARDL illustrate that, industrial sector, GDP growth, FDI and non-renewable energy consumption increase the Greenhouse Gas (GHG) Emissions in South Asian economies while GDP square and non-renewable energy consumption decrease the Greenhouse Gas (GHG) Emissions in South Asian economies.

Industrialization has positive role in greenhouse gas emissions, which illustrates that industrialization enlarges manufacturing, mining, fabrication and power - intensive services. In SAARC, most extra industrial sector energy requirement is still encountered by fossil fuels such as natural gas, coal, oil, so industrial growth pushes more greenhouse gases from fuel combustion. Empirical analyses of SAARC economies frequently find energy consumptions and industrialization to be foremost positive drivers of greenhouse gases emissions (Latief, et al., 2021). Further, some activities in industrial sector produce process releases in tallying to fuel burning, especially cement, steel, and assured chemical procedures, which are big, hard – to – abate sources of greenhouse gases and occasionally methane. Recent studies highlight planned increases and coal – heavy power for industry that will lock in difficult releases unless technologies alteration. Fast and speedy industrial sector growth advances electricity demand. Where grid additions are encountered by coal the carbon amount of supply increases and total nationwide releases increase sharply, a dynamic recognized in Bangladesh and somewhere else in the region. This finding is supported by the other recent studies, (Mosibzadeh, et al., 2024); (Mosibzadeh, et al., 2024); (Ahmed, et al., 2022); (Safdar, et al., 2021); (Kuang, 2021); (Wadanambi, et al., 2020); (Liu, & Bae, 2018); (Didenko, et al., 2017); (Vavrus, et al., 2008) and (Moomaw, 1996).

FDI also has positive role in greenhouse gas emissions, which illustrate that, Multinational Corporations companies (MNCs) often relocate their pollution – intensive industries to developing nations where environmental values and standards are less rigorous and compliance costs are reasonably low. The inflow of FDI often endorses the growth of large – scale manufacturing, mining, cement, and energy sectors that depend on heavily on fossil fuels. While FDI theoretically related with the transmission of advanced and cleaner technologies, in drill, developing economies frequently receive elder or unproductive "brown" technologies that subsidize to greater releases. This happens largely because of pathetic environmental rules and regulations, inadequate capacity to fascinate modern technologies, and the profit-oriented method of investors. In SAARC, FDI – led industries are typically export – driven, predominantly in production of textiles, leather, and fertilizer, which further intensifies energy consumption, transportation – related releases, and process – based greenhouse gases. Moreover, most SAARC economies lack robust environmental governance instruments, such as strict release standards, carbon pricing strategies, or mandatory clean technology acceptance. As a result, even when environmentally friendly technologies are available, foreign enterprises have little encouragement to utilize them, leading to an invasion of carbon – intensive or "Dirty FDI". This finding is supported by the other recent studies, (Miah, et al., 2025); (Amin, & Rahman, 2024); (Huang, et al., 2022); (Wang, et al., 2020); (Kastratović, 2019); (Liobikienė, & Butkus, 2019); (Lyeonov, et al., 2019); (Sapkota, & Bastola, 2017); (Shahbaz, et al., 2015) and (Omri, et al., 2014).

GDP has positive and GDP^2 has negative role in greenhouse gas emissions, which supports the hypothesis of Environmental Kuznets curve (EKC) in SAARC economies. The EKC (Environmental Kuznets Curve) hypothesis suggests that as an economy grows, environmental deprivation initially exaggerates but begins to decline after attaining a specific income threshold. During the initial stages of economic growth, nations prioritize industrialization and employment formation, often neglecting environmental worries. Heavy reliance on fossil fuels and resource intensive industries throughout this phase leads to snowballing levels of pollution and greenhouse gas (GHG) releases. However, as income continues to upswing, public demand for environmental fortification strengthens, prompting governments to contrivance stricter environmental rules and regulations, promote cleaner technologies, and encourage a shift toward less – polluting sectors like as services. At progressive stages of development, economies usually adopt renewable energy bases, improve energy competence, and enforce comprehensive environmental strategies, thereby reducing releases even as economic activity continues to enlarge. This finding is supported by the other recent studies, (Maneejuk, et al., 2020); (Ridzuan, 2019); (Mitić, et al., 2019); (Hove, & Tursoy, 2019); (Özokcu, & Özdemir, 2017); (Shahbaz, et al., 2013); (Ahmed, & Long, 2012); (Panayotou, 1993) and (Grossman, & Krueger, 1995).

Renewable energy has negative role in greenhouse gas emissions which illustrates that, the incorporation of renewable energy basis such as wind, solar, hydro, and biomass into the power mix helps to supernumerary electricity generation that would otherwise rely on fossil fuels like coal, oil, and natural gas, major providers to GHG emissions in the SAARC region. As the share of renewables upsurges, carbon releases from the power sector deteriorate accordingly. Moreover, cleaner electricity simplifies the electrification of sectors such as transportation, heating, cooking, and manufacturing, thereby reducing total lifecycle greenhouse gas releases. Renewable energy projects are often implemented alongside grid modernization efforts, including energy storage systems, digital management, and enhanced transmission networks, which improve efficiency and diminish losses associated with traditional thermal plants. Additionally, replacing diesel generators and biomass-based cooking systems with renewable alternatives helps lower methane and black carbon releases, both of which are potent short – lived climate pollutants. A steady and considerable renewable energy base also enables low – carbon industrial solutions like as electric heating and the use of green hydrogen, further cutting down process-related and fuel – based releases in manufacturing industries. This finding is supported by the other recent studies, (Maneejuk, et al., 2020); (Ridzuan, 2019); (Mitić, et al., 2019); (Hove, & Tursoy, 2019); (Özokcu, & Özdemir, 2017); (Shahbaz, et al., 2013); (Ahmed, & Long, 2012); (Panayotou, 1993) and (Grossman, & Krueger, 1995).

Non-renewable energy has positive role in greenhouse gas emissions, which illustrates that, energy from non – renewable sources, mainly coal, oil, and natural gas, are the foremost contributors to greenhouse gas releases in the SAARC region. When these fuels are scorched to generate electricity or power industries and transport systems, they discharge large amounts of GHG emissions. Because most SAARC economies heavily depend on coal – based power plants and imports of petroleum, enlarged non – renewable energy consumption openly results in advanced GHG discharges. In SAARC, industrial sectors are extremely energy – intensive and rely frequently on fossil fuels. As non – renewable energy consumption develops to meet industrial demand, process related emissions also increase. Most SAARC economies still depend greatly on coal – fired power plants for electricity generation. These plants are among the principal single emitters of CO_2 and other GHGs emissions. So, an upsurge in non – renewable energy consumptions, significantly increases total national GHG releases. This finding is supported by the other recent studies, (Rai, et al., 2025); (Zhang, et al., 2024); (Candra, et al., 2023); (Ponkratov, et al., 2022); (Chien, 2022); (Le, et al., 2020); (Deng, et al., 2020); (Maneejuk, et al., 2020); (Güney, 2019); (Al Araby, et al., 2019) and (Amponsah, et al., 2014).

The study provides some effective policy recommendations to the policymakers based on results and discussions. It is suggested that policy makers should give priority to boost the transition to clean and sustainable energy alternatives to reduce greenhouse gas and carbon emission. First, government should give subsidies, investment opportunities in solar, wind, and hydropower infrastructure by reducing taxes and less dependence on fossil fuels. Policymakers should adopt green industrial growth by promoting green cleaner production technologies, strengthening environmental regulations and supporting low carbon production through incentives like reducing taxes and giving subsidies. Moreover, focusing FDI toward green technology, clean energy, and sustainable infrastructure can guarantee that foreign investments reinforce emission reduction instead of contributing to environmental degradation. Regional alliance among countries, particularly within SAARC, in technology sharing, climate financing, and research initiatives can also increase mutual efforts against climate change. Ultimately, long-term emission reduction depends on a comprehensive strategy that blends renewable energy growth, cleaner industry, sustainable FDI, regulatory improvements, and regional

These policy implications are highly relevant and applicable to SAARC economies as well. Most SAARC countries face rising emissions due to rapid population growth, industrialization, urbanization, and heavy dependence on fossil fuels. Renewable energy adoption, energy efficiency, and cleaner industrial practices are essential for the region because SAARC countries collectively struggle with energy shortages, outdated technology, and limited environmental regulation enforcement. Green-focused FDI, regional climate cooperation, and carbon-pricing mechanisms can help SAARC nations transition to low-carbon development while sustaining economic growth. Therefore, implementing these policies would not only reduce emissions but also support sustainable development, improve energy security, and strengthen climate resilience across the SAARC region.

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