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Interactions among the primary causes of carbon dioxide emissions in selected south Asian countries: Does renewable energy mitigate carbon dioxide emissions?

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ABSTRACT

The primary aim of this study is to examine the relationship between economic growth (EG), financial development, renewable energy consumption and environmental pollution in South Asian countries (SAC). The "Autoregressive Distributed Lag (ARDL) model" applies panel data analysis from 1990 to 2021 in selected SAC. This study reveals that a 1 percent increase in financial development (FD) tends to increase 0.3356 percent of CO2 emissions. Renewable energy consumption (RE) essentially diminishes ecological contamination: a 1 percent expansion in RE will reduce 0.5878 percent of CO2. Expanded reception sources are related to a significant decrease in CO2 highlighting the capability of clean energy to advance manageable turns of events. The blunder rectification term remains at - 0.3741 with measurably critical outcomes which suggests that the speed of equilibrium is 37% to arrive at a drawn-out balance in SAC. We urge policymakers to find some kind of harmony between financial development and natural maintainability by advancing sustainable power projects and implementing stricter ecological guidelines. This study contributes to the literature by presenting empirical evidence on the environmental impact of economic and financial dynamics in a region experiencing rapid growth and development challenges.

Contribution/Originality: This study emphasises the need for financial deepening to be accompanied by sustainable practices (such as cleaner technology, renewable energy sources, and environmental regulations) to emphasize a balance of ecological sustainability and economic growth. Deepening alone will not result in significant environmental improvements. Urgent sustainable strategies are needed to address the environmental implications of rapid population growth.

1. INTRODUCTION

Environmental pollution remains a pressing issue worldwide with CO2 recognized as the primary factor behind global warming which has put people's lives at risk (Idroes et al., 2024). Meanwhile, the global economy is witnessing steady growth as more energy becomes available. Unfortunately, this rise in energy levels also results in a rise in greenhouse discharges further endangering the environment. Globally, energy use is forecast to grow by 1.3% in 2023 due to economic growth. It is projected that 2030 energy needs will rise by 60% with an associated increase in CO_2 emissions (World Energy Outlook, 2023). Preserving natural resources and reducing ecological pollution is crucial to ensure economic growth will not jeopardize environmental sustainability.

Environmental contamination creates a major challenge for both sustainable development and the ecological balance of South Asian countries (SAC). These nations thriving financial sectors, and a growing emphasis on green energy face a dilemma between development and environmental sustainability characterized by rapid economic growth (Azam, Uddin, Khan, & Tariq, 2022; Rahman, Voumik, Akter, & Radulescu, 2023). The test lies in offsetting monetary aspirations with the preservation of nature especially given the region's weakness in environmental change and ecological corruption. The rapid monetary development in South Asia has prompted the expansion of industrialization, urbanization and energy utilization (Majumder, Rahman, & Martial, 2022). While pursuing financial progress is crucial for achieving welfare, it often produces more environmental pollution. Industries and transportation are also sources of greenhouse gases and other toxins which are significant contributors to economic growth. The relationship between economic growth and environmental degradation prompts essential questions regarding the sustainability of existing development strategies (Majumder et al., 2022; Nahrin, Rahman, Majumder, & Esquivias, 2023). Monetary development which includes governments, markets, and economic expansion is the driving force of progress and has different effects on pollution in the environment.

On the one hand, monetary advancement can work with interests in cleaner innovations and sustainable power projects possibly lessening environmental pollution (Hu, Alola, Tauni, Adebayo, & Abbas, 2023). Expanded access to capital can speed up development and worsen environmental pollution. Recognizing the double-edged sword is crucial for devising strategies that promote financial growth while benefiting the environment (Pottier & Le Treut, 2023). Obtaining sustainable energy sources is crucial to reducing ecological pollution and addressing climate change. South Asian nations have started putting resources into environment-friendly power frameworks including solar, wind, and hydroelectric power (Dai & Xiong, 2023). Renewable energy utilization promises to reduce dependence on fossil fuels and decrease greenhouse gas emissions. However, integrating renewable energy into existing energy systems poses economic and technical challenges. The extent to which renewable energy can mitigate the environmental impacts of economic and financial activities remains an active area of research.

This research determines the impact of the monetary turn of events, commodities and populace development on natural contamination. It examines whether sustainable power utilization plays a role in diminishing ecological contamination. In addition, long- and short-term connections among these factors are expected to be observed in SAC. The essential targets of this examination are (i) to survey the effect of the monetary turn of events, commodities and populace development on ecological contamination. (ii) To evaluate the impacts of financial development and sustainable power utilization on ecological contamination and (iii) to examine the long- and short-term effects of the chosen factors on CO_2 discharge in SAC.

The current analysis intends to assess the effect of the monetary turn of events, the reception of sustainable power sources and monetary development on South Asia's environmental contamination while also analyzing the impacts of population development. Additionally, examining the relationships among economic growth, renewable energy (RE), financial development (FD), exports and population growth (PG) is essential for accurately assessing their impacts on environmental pollution. Understanding these correlations is crucial for policymakers, environmentalists and economists who aim to create strategies that balance economic development with environmental preservation. This research offers valuable insights for developing comprehensive policies that foster economic progress, financial stability and environmental sustainability in SAC. As the global economy expands and evolves, it is crucial not to neglect the significance of the environment. This research is well-timed given the necessity to preserve environmental equilibrium and reducing CO_2 emissions globally is one means of achieving this objective. This issue is significant because the rise of CO2 emissions is the primary contributor to climate change.

Pollution in SAC is influenced by several factors including economic growth, financial development, trade volume (exports) and population size (Kiani, Sabir, Qayyum, & Anjum, 2023; Padhan & Bhat, 2023; Ridwan et al., 2024). Addressing the pollution issue in this region requires a coordinated governmental strategy. The impact of economic expansion and financial development on pollution can be gradually reduced by adopting renewable energy sources and improving financial practices (Karlilar, Balcilar, & Emir, 2023). Although these factors initially contribute to increased pollution, they can be designed to mitigate their negative effects. This research seeks to address a gap in this field and show implications for academic and policymaking purposes.

The analysis comprises five identifiable parts. The initial part shows a comprehensive summary of the introduction. The second segment delves into literature analysis. The third part pertains to the methodology. The fourth part is dedicated to the analysis and discussion regarding the findings. The fifth and final part presents final thoughts and suggestions.

2. LITERATURE REVIEW

2.1. Economic Growth and Environmental Pollution

Emerging nations such as South Asia are often associated with negative environmental impacts as they develop. As these countries developed, they typically implemented stricter environmental regulations and adopted more efficient technologies, ultimately improving environmental quality. According to EKC theory, environmental harm rises initially as the economy grows but diminishes after a certain level of per capita income (Ridwan et al., 2024). Research by Panayotou (1993), Grossman and Krueger (1995) and Purwono et al. (2024) support this hypothesis. In SAC, urbanization and energy use have been identified as causing substantial growth in CO_2 emissions (Islam, 2021; Raihan, Voumik, Rahman, & Esquivias, 2023). Similarly, Sharma, Sinha, and Kautish (2021) reported that rising economies in South and Southeast Asia are responsible for the rising CO_2 emissions. This indicates the need for a policy framework balancing environmental and economic objectives. In South Asia, Dasgupta, Laplante, Wang, and Wheeler (2002) discover proof to validate the EKC. They argued that later stages of development could result in better environmental practices and less pollution while the early stages of FD lead to more pollution. Alam, Begum, Buysse, Rahman, and Van Huylenbroeck (2011) examined the impact of FD on CO2 emissions in South Asia and found a positive relationship. This suggests that CO_2 emissions rise as FD increases. Shahbaz, Solarin, Mahmood, and Arouri (2013) add urbanization and energy use to this study showing that South Asia's economic growth is currently associated with more environmental pollution.

The circular economy (CE) approach is a promising alternative to address these environmental challenges. The research conducted by Didenko, Klochkov, and Skripnuk (2018) and Sultana, Rahman, and Zimon (2024) highlights the central ideas of the CE which were distinct from the prevailing linear economic model. Nikanorova and Stankevičienė (2020) revealed that the European Union (EU) formulated an action plan to support its member states in implementing CE. Technological advancements and eco-innovations are essential for establishing a CE and addressing the challenges that impede its implementation. These challenges relate to money, law and people's attitudes (Nikanorova & Stankevičienė, 2020). People perceive CE as a means of growing the economy while benefiting the environment. Transitioning to CE and using existing materials will benefit the economy. The CE is also believed to provide numerous opportunities for businesses and consumers (Uvarova, Atstaja, & Korpa, 2020). Since the traditional monetary system is often criticized for its negative influence on the environment, transitioning to a CE has been asserted as a potential solution (Didenko et al., 2018).

2.2. Financial Development and Environmental Pollution

There are various ways in which financial development can influence the nature of the climate. For example, by putting resources into green advancements, making energy use more effective, and passing ecological regulations. Tamazian, Chousa, and Vadlamannati (2009) and Majumder and Rahman (2020) say that financial development can improve the climate by bringing about cleaner advancements and attracting Foreign Direct Investment (FDI) to observe stricter ecological guidelines Islam, Shahbaz, Ahmed, and Alam (2013). This study examines how monetary development in South Asia has influenced CO_2 emissions particularly through domestic credit to the private sector. Initially, increased credit may lead to higher emissions as industries expand. However, it can improve environmental performance over time by adopting better technologies and practices. These findings are supported by those reported by Voumik et al. (2023) and Raihan et al. (2023). Meanwhile, Ahmed, Rehman, and Ozturk (2017) discuss the different sides of monetary development. They suggest that increased economic activity may exacerbate pollution in the long term. It can facilitate the adoption of cleaner technologies and more energy-efficient processes.

2.3. Renewable Energy Consumption and Environmental Pollution

Using environmentally friendly power sources, including solar, wind, and hydroelectric power is crucial to lower greenhouse gas emissions and alleviate environmental changes. Marques and Fuinhas (2012) demonstrated that deploying more efficient power energy is related to reducing CO_2 emissions. Similarly, Sinha and Shahbaz (2018) investigated how using sustainable power lowers CO2 emissions in South Asia and their findings show a strong connection between them. This suggests that elevating the proportion of RE within the energy spectrum can significantly impact the environment. Meanwhile, Bhattacharya, Paramati, Ozturk, and Bhattacharya (2016) investigated the relationship between the use of RE, EG and CO_2 emissions in SAC and found that using RE lessens emissions and promotes EG. Similarly, Zaman, Shahbaz, Loganathan, and Raza (2016) propose a strategy that combines three ways of looking at how FD, EG and the application of efficient power energy impact the environment. Policies that support FD and EG should promote the use of RE to achieve sustainable development. South Asia faces both rapid EG and environmental challenges, making it crucial for policies to support FD and RE use. Policymakers should focus on making it easier for individuals to invest in renewable energy technologies (Akter, Voumik, Rahman, Raihan, & Zimon, 2023). In addition, Apergis and Payne (2010) demonstrated the importance of government backing and encouraging RE projects which can help the economy grow and protect the environment.

The impacts of EG, FD, population and trade on environmental pollution in SAC are complex and require further investigation (Minh, Ngoc, & Van, 2023). Adopting RE and improved financial practices can help mitigate these effects over time while EG and FD may initially lead to increased pollution (Han, Zeeshan, Ullah, Rehman, & Afridi, 2022). Therefore, a coordinated policy approach is crucial for promoting sustainable development in regions with minimal environmental impact (Ridwan et al., 2024). Although numerous research has explored the interplay between EG, FD, RE, and environmental pollution in SAC, existing studies have often examined these factors in isolation or failed to analyze their combined effects comprehensively. There is a need for a more integrated approach that examines how these variables collectively impact environmental pollution in South Asia. This research offers a comprehensive view of the region's challenges and potential solutions for sustainable development, encompassing India, Pakistan, Bangladesh, Sri Lanka, Nepal, Bhutan and the Maldives.

3. METHODOLOGY

3.1. Data and Model Specification

This research involves sourcing data from the "World Development Indicators," "Our World in Data," and "International Energy Statistics" for the selected South Asian countries such as Bangladesh, India, Pakistan, Sri Lanka, and Nepal. A linear model was developed using variables not previously examined such as population and globalization (e.g., trade). The analysis uses balanced panel data from 1990 to 2021.

$$CO_2 = f(GDPG, Renew, FD, Ex, PG) \quad (1)$$

In this equation, we use "CO_2 as a proxy for environmental pollution," where the units are in kilograms per 2010 US dollars of GDP. GDPG represents the "annual growth rate of GDP," and renew is the percentage of "total final energy consumption that comes from renewable sources." FD represents an indicator of financial development, specifically "domestic credit to the private sector as a percentage of GDP." Ex represents the current value of "exports of goods and services in US dollars." PG represents the annual population growth rate.

By taking a regular logarithm, the last econometric model is as follows:

$$lnCO_{2,it} = \alpha + \beta_1 lnGDPG_{it} + \beta_2 lnREn_{it} + \beta_3 lnFD_{it} + \beta_5 lnEx_{it} + \beta_4 lnPG_{it} + \mu_{it} \quad (2)$$

Variables t and i are used in this context to denote countries and periods, respectively. T denotes the count of periods and N denotes the number of countries. Variable t describes the observed period.

3.2. Panel ARDL

Pesaran and Shin (1999) introduced the ARDL strategy which was later expanded by Pesaran, Shin, and Smith (2001) to evaluate both short- and long-term linkage among variables. The ARDL method is versatile because it can be applied regardless of whether the data are integrated at the level of first difference or mixed order. Banerjee, Dolado, Galbraith, and Hendry (1993) further demonstrated that an Error Correction Model (ECM) can be developed using the ARDL approach. The ECM indicates how fast deviations from the long-run equilibrium are restored in the short run. The ARDL model identifies if a long-run relationship appears in variables and quantifies the speed at which variables return to equilibrium after a disturbance by incorporating the ECM.

3.3. Hypotheses of the Study

Various studies have demonstrated that economic growth affects carbon emissions in both positive and negative way. Although EG is frequently associated with improved expectations for everyday comfort and mechanical progression, it can also considerably influence CO_2 discharge. As economies expand, increased industrial activity, energy consumption and transportation contribute to higher greenhouse gas emissions. In developing countries, rapid industrialization and urbanization drive emissions, heavily relying on fossil fuels such as coal, oil, and natural gas. These energy sources are key contributors to CO2 emissions. As production and consumption grow in a developing economy, the number of factories, vehicles and power plants rises, all of which emit significant amounts of carbon dioxide. In addition, higher wages and further developed expectations for everyday comfort lead to expanded utilization of labor and products which frequently include carbon concentration (Pottier & Le Treut, 2023). For instance, more people may purchase vehicles, travel more frequently and consume more power, increasing CO_2 emissions.

In any case, it is critical to note that while monetary development can prompt higher CO_2 emissions, it also makes technological progress important to put resources into cleaner energy sources and more effective advancements (Tao, Sheng, & Wen, 2023). As economies grow, there is often a shift towards sustainable power and stricter ecological guidelines which can moderate the long-term effects of monetary development on CO_2. While monetary development will generally drive up CO_2 emissions initially, it also holds the potential to advance reasonable practices and advancements that can ultimately decrease carbon footprints. The relationship between economic growth and CO2 emissions is complex and multifaceted necessitating balanced approaches to ensure sustainable development. On the one hand, Arouri, Youssef, M'henni, and Rault (2012) and Anser, Alharthi, Aziz, and Wasim (2020) have shown that EG positively impacts CO_2. However, Jian, Fan, He, Xiong, and Shen (2019), Aye and Edoja (2017) and Atici (2009) noted that EG negatively affected carbon emissions.

H_1: Economic growth significantly affects CO_2 emissions in South Asian countries.

Renewable energy decreases carbon emissions according to research by Qi, Zhang, and Karplus (2014), Liu, Zhang, and Bae (2017), Didenko et al. (2018) and Rahman, Mohanty, and Rahman (2024).

H_2: Renewable energy significantly affects CO_2 emissions in South Asian countries.

Economic development often impacts environmental pollution. As financial systems advance, increased investment in industries and infrastructure can lead to higher pollution levels if not managed sustainably. In developing countries, economic growth typically results in greater access to credit and investment for businesses (Jian et al., 2019). Increased capital flow can spur industrial growth leading to the establishment of more factories and production facilities. These activities often rely on fossil fuels and other environmentally damaging resources, contributing to elevated air, water and soil pollution levels. Additionally, financial development promotes consumer credit growth enabling individuals to purchase more goods and services. This rise in consumption can result in greater waste production and higher energy use further exacerbating environmental pollution (Khan, Khan, & Muhammad, 2021). For instance, the proliferation of personal vehicles leads to higher CO2 emissions and greater pollution. Additionally, economic development often drives urbanization with people moving to cities in search of better opportunities. This rapid urban growth can put pressure on existing infrastructure resulting in increased waste, pollution and environmental degradation if not properly managed (Purwono et al., 2024). Zhang (2011) and Cheng, Ren, Wang, and Yan (2019) support that FD increases pollution. Shahbaz et al. (2013) and Saqib et al. (2024) demonstrate negative influences.

H_3: Financial development significantly affects CO_2 emissions in South Asian countries.

According to studies conducted by various authors including Cheng et al. (2019) suggests that exports are linked to increases in carbon emissions. This conclusion is validated by Anser et al. (2020) and Xu, Guan, Oldfield, Guan, and Shan (2024). Bosupeng (2016) found that exports also reduced carbon emissions.

H_4: Exports significantly affect CO_2 emissions in South Asian countries.

The consequence of population growth on CO_2 emissions has been researched by Aye and Edoja (2017), Rehman, Ma, Ozturk, and Ulucak (2022), Azam et al. (2022) and Anser et al. (2020) revealing that population growth positively impacts CO_2 emissions.

H_5: Population growth significantly affects CO_2 emissions in South Asian countries.

4. DATA ANALYSIS AND RESULTS DISCUSSION

Statistical and econometric methods provide various results which are presented below.

4.1. Descriptive Statistics, Panel Unit Root, and Optimum Lag Selection Criterion

Table 1 displays the statistical properties of South Asian countries' data including the *"mean, median, maximum, minimum, and standard deviation as well as skewness and kurtosis."* The probability values for LnREn, lnFD, and lnEx suggest a normal data distribution whereas the remaining variables are normally distributed with the first difference.

Table 1. Descriptive statistics of South Asian countries.

Summary statistics	$LnCO_2$	LnGDPG	LnREn	LnFD	LnEx	LnPG
Mean	-0.303	0.679	1.771	1.424	10.000	0.175
Median	-0.336	0.703	1.760	1.417	9.985	0.239
Maximum	0.148	1.011	1.978	1.772	11.674	0.471
Minimum	-1.024	-0.920	1.564	0.946	8.582	-0.981
Std. dev.	0.299	0.227	0.113	0.167	0.701	0.245
Skewness	-0.032	-3.365	0.328	-0.339	0.404	-1.782
Kurtosis	1.681	22.481	2.219	3.395	2.979	8.166
Jarque-Bera	8.787	2141.698	5.238	3.108	3.287	198.635
Probability	0.012	0.000	0.073	0.211	0.193	0.000

This study employed the "Levin, Lin, and Chu t* and Im, Pesaran, and Sin W-stat" tests for panel root unit tests. Unit root test findings are presented in Table 2. The discoveries imply that LnGDPG, LnREn and LnPG are stationary at I(0) while LnCO2, LnFD, and LnEx are stationary at I(1) proposing the utilization of the board ARDL approach for these nations. The ideal slack determination basis is shown in Table 3 for South Asian nations where ideal slack is picked in light of the Akaike Information Criterion (AIC) measure. The ideal slack for this model was 1.

Table 2. Panel unit root result.

Variables	Levin, Lin and Chut t*				Im, Pearson and Shin W-stat				
	Level		First difference		Level		First difference		Result
	T-stat (TS)	P value (P)	TS	P	T S	P	TS	P	
$LnCO_2$	-1.600	0.055	-4.111	0.000	-0.585	0.279	-6.438	0.000	I(1)
LnGDPG	-5.267	0.000	-5.934	0.000	-4.531	0.000	-7.853	0.000	I(0)
LnREn	-4.844	0.000	-1.555	0.060	43.878	0.000	-3.099	0.001	I(0)
LnFD	0.113	0.545	-1.255	0.105	1.134	0.872	-3.607	0.000	I(1)
LnEx	-0.539	0.299	-4.430	0.000	1.744	0.959	-4.271	0.000	I(1)
LnPG	-0.215	0.415	-5.847	0.000	0.812	0.792	-5.393	0.000	I(0)

Table 3. Optimum lag-length.

Lag	LogL	LR	FPE	AIC	SC	HQ
0	181.678	NA	8.48e-10	-3.861	-3.696	-3.794
1	862.250	1256.440	5.98e-16*	-18.027*	-16.869*	-17.560*
2	886.904	42.264	7.75e-16	-17.778	-15.626	-16.910
3	913.334	41.823	9.81e-16	-17.568	-14.422	-16.299
4	935.666	32.395	1.39e-15	-17.267	-13.129	-15.598
5	999.318	83.936*	8.24e-16	-17.875	-12.743	-15.805

Note: * indicates the 5% level of significance.

4.2. Estimates of Panel ARDL Model

Table 4 presents the results of the panel ARDL model detailing the distinct *"coefficients, t-statistics, and probability"* for SAC countries. According to the table, in the long-run, GDP growth in SAC is negatively but insignificantly co-integrated with CO_2. This implies that a 1 unit increase in LnGDPG will decrease 0.079 units of CO_2 in the SAC. The FD variable positively and significantly affects CO_2 in SA countries, with a 1 unit increase in LnFD by 0.336 units of CO_2. According to a finding by Alola, Olanipekun, and Shah (2023), Rahman et al. (2024) and Karlilar et al. (2023) LnREn fundamentally diminishes ecological contamination, as shown by the outcomes which showed that a 1-unit expansion in LnREn will diminish 0.588 units of CO_2 in South Asian nations. Exports also display a negative relationship with environmental pollution as shown in the table where a 1 unit increase in LnEx decreases CO_2 emissions by 0.096 units.

Table 4. Long- and short-term dynamics using panel ARDL.

Variables		Coefficients	T stat	Prob.
Long-run	LnGDPG	-0.079	-1.528	0.130
	LnFD	0.336	4.403	0.000
	LnREn	-0.588	-3.110	0.003
	LnEx	-0.096	-2.405	0.019
	LnPG	0.222	3.975	0.000
Short-run	ECT	-0.374	-2.761	0.007
	Δ LnGDPG	0.000	0.029	0.977
	Δ LnFD	-0.143	-1.750	0.084
	Δ LnREn	-2.283	-1.424	0.158
	Δ LnEx	0.027	0.386	0.700
	Δ LnPG	0.416	0.768	0.445
	Constant	0.412	2.927	0.004

Furthermore, according to a finding supported by Voumik, Hossain, et al. (2023), Rehman et al. (2022) and Azam et al. (2022) the results demonstrated that population growth significantly and positively affects environmental pollution where a 1 unit increase in LnPG tends to increase 0.222 units of CO_2 in SA countries. The Error Correction Term (ECT) esteem addresses the speed of change in disequilibrium rectification and the outcomes demonstrate that ECT remains at − 0.374 with genuinely huge outcomes suggesting that the speed of revision disequilibrium change is 37% to arrive at a draw-out balance. In the short-run, LnGDPG, LnEx, and LnPG are decidedly connected with CO_2 whereas LnFD and LnREn are adversely associated with ecological contamination in South Asian nations.

4.3. Country-Wise Impact

The coefficient of ECT in Bangladesh was negative suggesting that the speed of acclimation to remedy disequilibrium to accomplish long-term harmony was 85%. In the short run, GDP growth and exports positively impact CO_2 in Bangladesh whereas financial development, RE and population growth negatively affect CE in Bangladesh. The country-wise impact of the short-run dynamics is shown in Table 5. In India, the coefficient of ECT is significant suggesting that the speed at which the economy adapts to the adjustment disequilibrium to accomplish a long-term balance is 13%. Population development in India is emphatically connected with CE while gross domestic product development, FD, RE and commodities has adverse consequences on CE in the short-run. These discoveries are reliable with those of Rahman, Voumik, Rahman, and Majumder (2024).

Table 5. Short-run dynamics of the cross-sectional unit.

Variables	Coefficient	t-statistic	Prob.
Bangladesh			
ECT	-0.85	-76.78	0.00***
D(LnGDPG)	0.01	18.21	0.00***
D(LnFD)	-0.26	-37.87	0.00***
D(LnREn)	-1.73	-32.14	0.00***
D(LnEx)	0.00	0.02	0.99
D(LnPG)	-0.27	-13.40	0.00***
C	0.95	2.60	0.08
India			
ECT	-0.13	-21.65	0.00***
D(LnGDPG)	-0.01	-149.34	0.00***
D(LnFD)	0.00	-0.13	0.90
D(LnREn)	-0.44	-3.58	0.04*
D(LnEx)	-0.16	-44.73	0.00***
D(LnPG)	2.57	1.65	0.20
C	0.24	7.12	0.01**
Pakistan			
ECT	-0.09	-20.14	0.00***
D(LnGDPG)	-0.01	-41.02	0.00***
D(LnFD)	0.01	1.91	0.15
D(LnREn)	-0.29	-2.72	0.07
D(LnEx)	-0.06	-12.17	0.00***
D(LnPG)	0.04	0.31	0.78
C	0.12	10.18	0.00***
Sri Lanka			
ECT	-0.40	-21.85	0.00***
D(LnGDPG)	-0.01	-5.46	0.01**
D(LnFD)	-0.06	-22.27	0.00***
D(LnREn)	-0.34	-1.17	0.33
D(LnEx)	0.11	1.60	0.21
D(LnPG)	-0.08	-60.04	0.00***
C	0.41	3.73	0.03*
Nepal			
ECT	-0.40	-91.63	0.00***
D(LnGDPG)	0.02	79.25	0.00***
D(LnFD)	-0.40	-19.42	0.00***
D(LnREn)	-8.60	-4.45	0.02*
D(LnEx)	0.25	17.92	0.00***
D(LnPG)	-0.18	-35.57	0.00***
C	0.36	4.70	0.02*

Note: * Indicates significance at the 5% level. ** Indicates significance at the 1% level, *** Indicates significance at the 0.1% level.

In Pakistan, the ECT is negative demonstrating that the speed at which the economy acclimates to the revision disequilibrium to arrive at a long-term balance is 8%. The findings conclude that FD and population growth are positively associated with CE in Pakistan whereas GDP growth, RE and exports negatively impact CE in the short run. In Sri Lanka, the outcomes demonstrate that the ECT is negative and genuinely critical recommending that the velocity of adjustment to the rectification disequilibrium to arrive at a long-term balance is approximately 40%. In the short -run, trade positively impacts CE in Sri Lanka while gross domestic product development, RE, FD and population development exhibit adverse consequences for CE. ECT shows a negative significance suggesting that the economy's speed at which it adjusts to correct any disequilibrium and reaches long-term equilibrium is approximately 40% as indicated in the findings presented in Table 5 from Nepal. In the short- run, GDP growth and exports in Nepal were positively associated with CO_2 emissions. However, FD, RE and population growth negatively impacted CE.

4.4. Findings and Hypothesis Analysis

In the South Asian region, the analysis of the hypotheses reveals varying impacts of economic factors on CO_2 emissions. According to Table 4, economic growth (H1) appears to exacerbate CO_2 emissions. This relationship is not statistically significant aligning with the conclusions of Jian et al. (2019), Aye and Edoja (2017) and Atici (2009) which suggest that EG does not consistently affect environmental pollution. In contrast, renewable energy consumption (H2) significantly and negatively affected CO2 emissions supporting H2 and aligning with earlier research by Qi et al. (2014), Liu et al. (2017) and Bosupeng (2016). Financial development (H3) negatively influences CO2 emissions in SAC, thus supporting H3. This discovery aligns with those of Shahbaz et al. (2013), Tao et al. (2023), and Ghorashi and Alavi Rad (2018). Export activities (H4) also reflect a significant and negative consequence for CO_2 emissions supporting H4 and corroborating the results of Martínez-Zarzoso, Bengochea-Morancho, and Morales-Lage (2007). However, according to Aye and Edoja (2017) the effect of population growth (H5) on CO2 emissions was positive and significant. Thus, H5 predicts a significant effect. It does not reject the notion that population growth exacerbates CO2 emissions confirming the findings within the context of the SAC region.

5. CONCLUSION AND RECOMMENDATIONS

The global economy's expansion driven by increased energy production also raises emissions and poses a threat to the environment. This study examines the impact of economic growth, renewable energy (RE), and financial development (FD) on pollution in South Asian countries. It also explores how population growth and exports affect pollution, and the short- and long-term implications of these factors on CO2 emissions in the region. We used balanced panel data from 1990 to 2021 for this analysis. Our findings indicate that GDP growth, RE, and population growth in South Asian countries are stationary at I(0) while CO2, FD and exports are stationary at I(1). This mixed-order integration suggests the use of the Panel ARDL approach. Optimal lag selection in this analysis yields a value of 1.

The analysis suggests that GDP growth and CO2 emissions exhibit a negative but insignificant cointegration relationship in the long run. In particular, an expansion in EG by one unit is related to a reduction in CO_2 by 0.079 units. Moreover, the discovery shows that FD decidedly affects CO_2 emissions in South Asian nations. The discovery shows that a one-unit expansion in FD will generally build CO_2 by 0.336 units. Similarly, the utilization of sustainable power adversely affects ecological contamination with the outcomes demonstrating that a one-unit expansion in sustainable power prompts a decrease in CO_2 by 0.588 units. Exports are likewise observed to be adversely connected with ecological contamination; an expansion in trade by one unit is related to a decline in CO_2 by 0.096 units. Moreover, the outcomes show that population development emphatically affects ecological contamination with a one-unit expansion in population development prompting an expansion in CO_2 by 0.226 units.

The ECT esteem mirrors the speed of disequilibrium rectification change and it remains at - 0.374 with measurably huge outcomes showing that the speed of revision disequilibrium change is 37% to arrive at a draw-out balance. In the short run, EG, exports and population growth are emphatically connected with CO_2 while FD and RE are adversely connected with natural contamination in South Asian nations.

We propose several policy strategies to address environmental pollution in South Asian countries based on the research findings. First, targeted management of financial development and population growth is essential. Effective policies should address their impacts on CO_2 emissions given their positive correlation with environmental pollution. Special attention to these factors can help mitigate their adverse effects. Expanding the use of renewable energy sources is crucial for reducing pollution. Supporting the adoption of sustainable power such as solar and biomass energy can significantly help in controlling CO2 levels. Policies should focus on increasing the share of renewable energy in the overall energy mix. Investment in research and development (R&D) for sustainable energy technologies is also important. Advancing technological innovation can boost the adoption of renewable energy and contribute to environmental preservation. Lastly, balancing the expansion of exports with environmental impact is necessary. Increasing exports is important; it should be done with consideration of the environmental consequences. Policies should aim to reconcile export growth with measures to reduce environmental degradation. South Asian countries can better manage environmental pollution while fostering sustainable economic development by implementing these strategies.

6. IMPLICATIONS OF THE STUDY

The outcomes of this research have far-reaching strategies for policymaking, economic planning, and environmental strategies in South Asian countries. Remarkably, the positive interaction between contemporary economic aspects and CO_2 emissions decreases the critical need for stringent administrative frameworks and the application of cleaner technologies. As significant contributors to emissions, modern sectors should prioritize strategies that enhance the reduction of carbon emissions through technological advancements and productivity improvements. Furthermore, the demonstrated reduction in carbon dioxide emissions from renewable energy sources highlights the crucial role of environmentally friendly power in achieving environmental sustainability. The strategy should focus on developing sustainable energy frameworks, such as solar, wind, and hydroelectric power to replace or enhance fossil fuel-derived energy sources. This shift contributes to reducing ozone-depleting substance emissions, improving energy security, promoting green practices and causing the overall economic transformation.

This research highlights the complex relationship between economic growth and carbon dioxide emissions underscoring the need for sustainable development practices to decouple economic advancement from environmental degradation. Embracing green technologies, enhancing energy efficiency, and implementing carbon valuation systems are crucial strategies for achieving this separation. Financial policies that incentivize low-carbon choices for businesses and consumers should also be considered. Furthermore, regional cooperation within South Asia can enhance the effectiveness of these strategies. By sharing technology, information, and best practices, countries in the region can accelerate the adoption of renewable energy and emission-reduction measures. Establishing local environmental goals and monitoring frameworks will help ensure accountability and progress toward collective sustainability objectives.

7. LIMITATIONS AND FURTHER STUDY

This study is limited to a specific set of South Asian countries due to constraints in data availability which prevent the inclusion of additional nations. Further research is warranted to look into the effects of environmental pollution in all countries and to incorporate additional variables such as globalization, green finance, and green technologies among others. Recent studies have highlighted non-linear relationships between economic aspects, such as GDP growth and environmental quality. Moreover, alternative methodologies should be employed to address the endogeneity issues. Future studies could investigate these non-linear relationships and explore alternative approaches to this problem.

List of Abbreviations:
ARDL = Autoregressive Distributed Lag.
CE = Circular economy.
CO_2 = Carbon dioxide emission.
ECT = Error Correction Term.
EG = Economic Growth .
EKC = Environmental Kuznets Curve.
EU = European Union.
FD = Financial Development.
GDP = Gross domestic product.
PG = Population Growth.
RE = Renewable Energy.
SAC = SAC.

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