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Investigating the Effect of Renewable Energy Utilization and Trade Openness Towards the Economic Growth and Environmental Quality in South Asia: A Comparative Study for South Asian Countries

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Abstract
This study aims to investigate the relationship between trade openness and the use of renewable energy sources and South Asia's economic growth and environmental quality. Since renewable energy offers a more sustainable and environmentally friendly option than fossil fuels, it becomes essential to attaining sustainable development. Using renewable energy has grown in popularity as a global solution to the urgent problems of energy security, climate change, and environmental sustainability. Renewable energy must be used by South Asian nations in order to reduce greenhouse gas emissions, maintain long-term energy security, and promote economic resilience. Incorporating renewable energy could enhance the country's energy situation, lessen dependency on imported fossil fuels, and open up new business prospects. Data on the use of renewable energy is gathered for the variable of renewable energy use. Data regarding GDP is gathered for the gross domestic product variable using current US dollars. The Energy Information Administration is the source of the data regarding the use of renewable energy (EIA). Additionally, the World Development Indicators database (WDI) is where the GDP and trade openness data are gathered. The following nations are represented in the data, which was gathered between 2001 and 2020: Bangladesh, India, Nepal, Sri Lanka, and Pakistan. We investigated the long-term relationship between energy consumption, economic growth, and environmental quality in this analysis using the Panel ARDL approach. The dependent variables in the equation above are the environmental quality and economic growth of the Asian developing nations that were chosen for analysis. According to the study's conclusion, TO, GDP, and RNW have long-term negative effects on the environment since they raise CO2. Conversely, RNW reduces CO2, however the effect is negligible compared to other relevant variables. While the results of the CD test show the presence of CSD, the Pedroni Panel Cointegration Test reveals long-run cointegration of a series. The correlation matrix displays the relationship between the variables. The result showed how strongly, negatively, or positively the factors linked with one another. Additionally, there is a substantial positive correlation between GDP and carbon dioxide, its dependent variable. Additionally, RNW are found to be directly related to one another. Both the TO and GDP have a strong and direct correlation, and there is a positive and significant relationship between GDP and RNW. The other cross-sections are connected to this one. They are interdependent and have an impact on one another. Using South Asia as a focus, this study looks at how trade openness and the use of renewable energy affect environmental quality and economic growth in nations including Bangladesh, India, Nepal, Bhutan, and the Maldives.

Keywords: Renewable Energy Utilization, Trade Openness, Economic Growth, GDP, Environmental Quality, CO2 Emission

1. Introduction

The South Asian region which includes countries like Bangladesh, India, Nepal, Bhutan, and the Maldives is well-known for its rapidly growing population, rapidly expanding economy, and rapidly rising energy requirements. These nations face the challenging challenge of advancing their economies while minimizing the environmental harm that traditional energy consumption is usually associated with. Renewable energy becomes crucial to achieving sustainable development since it provides a more environmentally friendly and sustainable alternative to fossil fuels. As a global answer to the pressing issues of energy security, climate change, and environmental sustainability, the usage of renewable energy has become more and more popular (Strielkowski et al., 2021). South Asian countries need to switch to renewable energy sources in order to cut greenhouse gas emissions, preserve long-term energy security, and foster economic resilience. The integration of renewable energy might improve the nation's energy picture, reduce reliance on imported fossil fuels, and provide new economic opportunities (Arif et al., 2022). But trade liberalization also has a significant effect on the economic and environmental performance of South Asian nations. By facilitating the exchange of goods, services, and technologies, trade liberalization fosters efficiency and innovation and accelerates economic growth. On the other hand, the consequences of increased trade activity on the environment are complex and multifaceted. Even though trade can promote the adoption of greener technologies and environmental standards, it can also lead to increased resource exploitation and environmental harm if it is not adequately regulated (Cai et al., 2020). This study aims to investigate the effects of trade openness and renewable energy consumption on South Asia's economic growth and environmental quality. This research looks at a number of South Asian nations to shed light on the interactions between these variables and offer suggestions for the most practical measures that can be taken to achieve

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sustainable development in the area (Xu et al., 2023). Using econometric models to evaluate data from South Asian nations, the research will look at the connections between trade policies, economic performance, environmental impacts, and the uptake of renewable energy.

Large-scale investments needed for renewable energy projects are frequently difficult to finance in South Asian nations due to a lack of adequate financial resources. Infrastructure for renewable energy, such wind turbines, hydropower facilities, and solar panels, could not be initially economical. Obtaining money is still difficult, despite its importance. When it comes to having access to cutting edge renewable energy technologies, the region is behind (Ghorashi and Maranlou, 2021). Due to a lack of technical expertise, many South Asian nations still rely on antiquated methods of generating, managing, and sustaining renewable energy systems. The adoption of increasingly effective and efficient renewable energy sources may be hampered by this technological lag. South Asia is most likely to be impacted by the effects of climate change, which include extreme weather, rising sea levels, and changed agricultural methods (He et al., 2021). Degradation of the environment, such as soil erosion and deforestation, exacerbates these vulnerabilities. Although renewable energy can assist with certain environmental issues, the region's susceptibility to the effects of climate change is a significant challenge. The energy-intensive industries and fossil fuel imports are often major sources of income for the economies of South Asia. Restructuring these economic linkages in order to transition to renewable energy may cause disruptions in the short term (Salam et al., 2020). Finding a balance between the shift to sustainable energy sources and economic growth is a challenging task.

Regarding the relationship between renewable energy, trade openness, economic progress, and environmental quality, particularly with regard to South Asia, many problems remain unsolved. Earlier studies have focused on individual states or regions outside of the continent rather than doing a comparative analysis across South Asian nations. This is a critical omission because the unique socio-economic and geopolitical circumstances of South Asian countries necessitate specialist research in order to gain a deeper understanding of these processes (Shah, 2021). Moreover, the majority of research conducted to far has taken a partial approach that considers the combined effects of trade openness and the usage of renewable energy on environmental quality, instead of concentrating on the specific advantages of either strategy alone. This study aims to bridge this gap by investigating the relationship between trade policy and the utilization of renewable energy. Analyzing trade policy is crucial to developing integrated plans for sustainable development (Murshed, 2020). Furthermore, it is challenging to draw conclusions regarding the long-term effects of trade openness and the adoption of renewable energy because few longitudinal research look at the temporal dimensions of these linkages. Our work will use time-series data to provide a dynamic and complicated understanding of these linkages throughout time, thereby filling this knowledge gap. The literature's lack of pertinent policy implications further restricts the applicability of the research (Ike et al., 2020). Our work intends to reduce this constraint by providing policymakers with important information to build successful and sustainable policies.

A comparison of other South Asian countries, including Bangladesh, India, Nepal, Bhutan, and the Maldives, is included in the study's scope. In order to identify trends that are both national and regional in nature, the study examines these countries. The consequences of trade openness and the adoption of renewable energy will be examined simultaneously using an integrated methodology to give a thorough picture of their combined influence on environmental quality and economic growth. The study will also use time-series data to record long-term trends and changes and offer greater insights into the lifetime of these interactions (Cusser et al., 2021). The methodology will make use of advanced econometric models and statistical techniques to ensure reliable and trustworthy outcomes. The ultimate objective of the project is to significantly advance the disciplines of trade economics, renewable energy, and environmental studies in the setting of South Asia (Cusser et al., 2021). Additionally, it seeks to offer policymakers practical guidance on how to promote sustainable development in the region.

2. Literature Review

2.1. Economic Growth

South Asia, which comprises countries like India, Pakistan, Bangladesh, Sri Lanka, Nepal, Bhutan, and the Maldives, has experienced varying degrees of economic growth during the last several decades. Because of its many economic structures and stages of development, this region provides an excellent environment for researching the factors driving economic growth. The literature on the economic development of South Asian countries emphasizes a number of crucial subjects, such as the value of trade openness, human capital, top-notch institutions, and infrastructural development (Cusser et al., 2021). The significance that trade openness plays in accelerating economic growth in South Asian countries has been the subject of numerous studies. Scholars such as (Mathes et al., 2021)have discovered positive relationships between trade liberalization and economic expansion. They contend that increased trade openness fosters innovation and technology inflow, boosts productivity, and establishes competitive marketplaces. For instance, greater exports and foreign direct investment (FDI) fueled India's economic growth during the 1990s economic liberalization policies (Chu et al., 2023). However, not every country in South Asia associates commercial openness with economic expansion. For example, although Bangladesh's expanding textile sector benefits from trade, the country has struggled with trade

diversification and dependence on a single industry. Like Bhutan, Nepal is a landlocked nation with a smaller economy that has not been able to take advantage of commercial openness due to physical and logistical constraints (Reckling et al., 2021).

The role that human capital plays in the economic development of South Asia has also been the subject of research. Studies by (Eyüboğlu and Uysal, 2022) highlight how critical better health and education are to economic expansion. Due to significant investments in healthcare and education made by Sri Lanka and other South Asian countries, there has been steady economic growth and comparatively high human development indices (Abeysekara and Bandara, 2022). Conversely, less developed human capital has hurt other South Asian countries like Bangladesh and Pakistan, limiting their potential for economic growth. Gender disparities in education, access to healthcare, and educational standards remain significant barriers, according to (Kumar et al., 2022a). These variations demonstrate how important targeted efforts to improve human capital are for encouraging long-term economic growth.

Institutional quality, encompassing aspects such as governance, political stability, and regulatory frameworks, is a significant determinant of South Asia's economic success. According to (Dharmadasa and Karunarathna, 2022), robust institutions are necessary for sustained economic growth. In South Asian countries, better institutional frameworks are usually linked to better economic performance. India's economic reforms after 1991, which included significant improvements in governance and regulatory frameworks, have been credited with the country's steady economic growth. However, due in part to the nation's unstable political environment and weaker institutional framework, Pakistan's economic growth has been more erratic. Like the Maldives, the nation's political and institutional volatility has affected investor confidence and economic stability (Khan, 2022).

2.2. Environmental Quality

South Asia, which includes countries like India, Pakistan, Bangladesh, Sri Lanka, Nepal, Bhutan, and the Maldives, is experiencing tremendous economic growth and urbanization, posing significant environmental issues. The region's environmental quality is influenced by several factors, including population growth, industrialization, and climate change. This review of the literature looks at the environmental condition of countries in South Asia, paying special attention to issues including deforestation, air and water pollution, climate change, and government responses. Air pollution is one of the biggest environmental issues facing South Asia. Large cities, such as Delhi, Dhaka, and Karachi, frequently rank among the most polluted in the world (World Health Organization, 2018). As per (Ahmad et al., 2022) findings, air pollution in India is a significant contributor to respiratory ailments and premature mortality, hence having an adverse effect on health. Similar conditions have been observed in Pakistan and Bangladesh, where rising industrialization and urbanization have exacerbated issues with air quality (Ahmad et al., 2022). Even while regulatory measures have been put in place, such India's National Clean Air Programme and Pakistan's stricter emission laws, implementation and enforcement remain significant problems.

Water contamination is another major environmental problem in South Asia. The region's rivers and aquatic bodies are seriously degraded as a result of inadequate sewage treatment, agricultural runoff, and industrial effluents (Ahmed et al., 2022). For instance, the extremely contaminated Ganges and Yamuna rivers provide drinking water, agricultural, and sanitary facilities for millions of people in India. Bangladesh faces severe problems with water contamination, particularly due to the presence of dangerously high levels of arsenic in the country's groundwater (Khan et al., 2021). Due to industrial pollution and excessive Indus River exploitation, Pakistan's water supply and quality are decreasing.

In South Asia, deforestation and land degradation are major problems caused by population growth, increased agricultural production, and logging. Reduced forest cover has a major impact on local livelihoods, biodiversity, and climate regulation. Deforestation in Nepal has been connected to fuelwood gathering and agricultural encroachment, which results in soil erosion and biodiversity loss (Chaudhary et al., 2023). Although illicit logging and land conversion continue to be problems, India has achieved some headway in its afforestation and reforestation efforts (Kumar et al., 2022b). In contrast, Bhutan's community-based forest management and robust conservation policies have allowed it to preserve a high percentage of forest cover. The effectiveness of Bhutan's strategy emphasizes how crucial it is to include local communities in conservation initiatives. South Asia is particularly vulnerable to the effects of climate change, which are already being felt in the region in the form of more frequent and intense extreme weather events like droughts, cyclones, and floods (IPCC, 2014). High population density, poverty, and the region's reliance on agriculture—which is extremely vulnerable to climate change—all contribute to the region's susceptibility (Kumar et al., 2022b). Bangladesh is especially susceptible to cyclones and rising sea levels, which endanger agricultural and coastal residents. Rising temperatures causing glacier melt in the Himalayan area, particularly Nepal and Bhutan, increase the risk of glacial lake outburst floods. According to (Richards et al., 2022), adaptive measures like early warning systems, community-based adaptation, and climate-resilient infrastructure are essential yet expensive and call for international collaboration.

Community-based strategies, financial incentives, and regulatory measures are frequently used in South Asian policy responses to environmental concerns, despite country variances in these approaches. In India, programs like the National Action Plan on Climate Change and the Swachh Bharat Mission aim to improve sanitation and

fight climate change, respectively (Government of India, 2008). However, barriers to policy implementation usually include inefficient bureaucracy and a lack of agency cooperation (Richards et al., 2022). While Pakistan's National Climate Change Policy and Bangladesh's Climate Change Strategy and Action Plan offer frameworks for addressing environmental issues, political turbulence and resource constraints hinder their respective implementation (Chapagain and Aase, 2020). Regional cooperation has been hampered by geopolitical disputes and competing national agendas, but it can be strengthened through organizations like the South Asian Association for Regional Cooperation (SAARC) to address environmental issues.

2.3. Trade Openness

The openness of trade laws, the lowering of tariffs, and the promotion of foreign direct investment (FDI) are examples of trade openness, which has been a major factor in South Asia's economic change. The economic effects, difficulties, and policy ramifications of trade liberalization are extensively covered in the literature on trade openness in South Asian nations. Examining the experiences of major South Asian nations—India, Pakistan, Bangladesh, Sri Lanka, Nepal, Bhutan, and the Maldives—this survey highlights the advantages and difficulties of trade liberalization. A number of South Asian nations have seen significant economic growth as a result of trade liberalization. India's economic reforms in 1991, with a focus on trade liberalization, led to a surge in GDP growth, an increase in foreign investment, and economic diversification (Panagariya, 2022). Studies by (Panagariya, 2022) highlight how trade openness has greatly boosted India's economic dynamism by encouraging innovation and productivity gains.

Trade openness has been essential in Bangladesh's growth of the textile and apparel sector, which is a significant source of employment and export revenue for the nation. Market access and competitiveness have been made easier by the removal of trade obstacles and preferential trade agreements (Islam, 2021). Trade liberalization has benefited sectors such as agriculture and textiles in Pakistan, albeit with uneven outcomes. But obstacles like erratic trade laws and unstable political environments have prevented trade liberalization from reaching its full potential (Islam, 2021). Beginning in the late 1970s, trade liberalization in Sri Lanka led to notable economic growth, export diversification, and an increase in foreign direct investment, especially in the industrial and services sectors (DiMenna, 2022). Trade openness in South Asia has encountered a number of difficulties despite its advantages. Common barriers include limited infrastructure, regulatory constraints, and structural flaws. Trade liberalization in India has worsened regional differences and income inequality notwithstanding its initial success (Ali et al., 2022). Small farmers have been particularly affected by the competition from less expensive imports in the agriculture industry (Ali et al., 2022). Bangladesh is susceptible to changes in the global market and competition because of its reliance on the textile sector. Concerns over the sustainability of trade-driven growth were raised by the Rana Plaza incident in 2013, which brought attention to the issues around labor standards and working conditions (Islam, 2024). Pakistan's economy is vulnerable to outside shocks due to its over-reliance on a small number of export goods and lack of diversification.

Due to their landlocked location and restricted access to markets, smaller economies like those of Nepal and Bhutan suffer particular difficulties. These nations' reliance on the infrastructure of their neighbors and logistical limitations frequently impede trade liberalization (Islam, 2024)). The Maldives confronts issues with environmental sustainability and foreign economic dependency because of its heavy reliance on tourism (Park-Poaps et al., 2021). The body of research emphasizes that in order to optimize the advantages of trade openness, supportive institutional frameworks and policies are crucial. Infrastructure investment, increased regulatory efficiency, and innovation promotion are examples of competitiveness-boosting strategies that should be incorporated into effective trade policy. To maintain the benefits of trade openness, India must implement policies that enhance logistics, cut red tape, and assist small and medium-sized businesses (SMEs) (Richards et al., 2022). To sustain growth and reduce the dangers associated with an over-reliance on the textile sector, Bangladesh must invest in human capital, improve labor standards, and diversify its product offerings (Rahman, 2023). To fully utilize economic openness in Pakistan, structural difficulties must be resolved, political stability must be maintained, and consistent trade policies must be put in place (Rahman, 2023). Overcoming obstacles connected to trade can also be greatly aided by regional integration and cooperation. Greater intraregional trade and collaboration could be facilitated by the South Asian Association for Regional collaboration (SAARC), despite political conflicts and a lack of

2.4. Renewable Energy

Worldwide, there has been a surge in the use of renewable energy sources as nations want to reduce their carbon footprint, improve energy security, and foster sustainable development. Because of its wealth of natural resources, South Asia—which includes nations like India, Pakistan, Bangladesh, Sri Lanka, Nepal, Bhutan, and the Maldives—has a lot of promise for the development of renewable energy. The current situation, difficulties, and future potential of renewable energy in South Asian nations are examined in this literature review, with particular attention to biomass, solar, wind, and hydro energy (Mitra et al., 2023). There are abundant renewable energy resources in South Asia. When it comes to the capacity for renewable energy, especially solar and wind power, India dominates the region. With a target of 100 GW by 2022, the National Solar Mission, which was introduced in 2010, seeks to position India as a global leader in solar energy (Ministry of New and Renewable Energy, 2019).

India has a sizable wind energy industry, with Gujarat and Tamil Nadu having the highest installed capacity (GWEC, 2018).

Bangladesh has advanced its solar energy industry, especially with solar home systems (SHS) that power remote communities. Millions of SHS have been successfully placed by the nation's Infrastructure Development Company Limited (IDCOL), increasing energy access and lowering dependency on conventional biomass ((Cusser et al., 2021). Pakistan has started a number of initiatives, like the Quaid-e-Azam Solar Park and Jhimpir Wind Corridor, to harness renewable energy due to its abundant solar and wind resources (Khan et al., 2020). An important part of Nepal's and Bhutan's energy mix is hydropower. Due to political and physical obstacles, Nepal has only developed a small portion of its estimated 83,000 MW of latent hydropower potential (Khan et al., 2020). Bhutan's economy depends heavily on the export of electricity to India, which it has done by harnessing its hydropower resources (Hulio et al., 2022). With investments in wind and solar energy, Sri Lanka has diversified its energy mix with the goal of achieving 100% renewable energy by 2050 (Sri Lanka Sustainable Energy Authority, 2019). As a tiny island nation with particular difficulties, the Maldives has also looked at solar and wind energy to lessen its reliance on imported diesel and improve energy security (Mahmood, 2023). Notwithstanding the advancements, a number of obstacles remain in the way of South Asia's widespread use of renewable energy. Budgetary limitations are a significant obstacle. Investment is discouraged by the high initial costs of renewable energy projects and the difficulty in obtaining funding (Mahmood, 2023). Because of their limited financial means, less developed nations like Bangladesh and Nepal are especially affected by this problem. Infrastructure and technological constraints also provide serious difficulties. Many South Asian nations lack the sophisticated technology and trained labor needed to create and maintain effective renewable energy systems (Khalid et al., 2023). Furthermore, it is challenging to incorporate renewable energy into the national grid in nations like Bangladesh and Pakistan due to inadequate grid infrastructure (Jabeen et al., 2021). Development of renewable energy is further complicated by legislative and regulatory obstacles. Investor confidence is weakened and project implementation is slowed down by inconsistent regulations, bureaucratic red tape, and a lack of long-term planning (Jan et al., 2023). For instance, despite India's lofty goals for renewable energy, delays and inefficiencies have resulted from legislative and policy obstacles (Naveed et al., 2022). Notable are the social and environmental challenges. Large-scale solar and wind project land acquisition may result in local community disputes and displacement. It's also necessary to address environmental issues, such as how hydropower affects river ecosystems and biodiversity (Naveed et al., 2022).

South Asian nations have launched a number of initiatives and policy measures to address these issues. To encourage investment in renewables, India's Renewable Purchase Obligation (RPO) requires power distribution firms to purchase a specific amount of their energy from renewable sources (Rashıd, 2020). In order to promote the growth of renewable energy, Bangladesh has instituted feed-in tariffs and other financial incentives (Qazi et al., 2020). In South Asia, regional collaboration might be crucial to the advancement of renewable energy. Energy security and economic development can be improved by cross-border energy trade, such as the sale of hydropower to India from Bhutan and Nepal (Yun and Kim, 2010). The goal of programs like the South Asian Association for Regional Cooperation (SAARC) Energy Center is to foster information sharing and regional cooperation (SAARC, 2014). Future prospects for renewable energy in South Asia are bright, but they will need careful planning and consistent work. Accelerating the adoption of renewable energy requires favorable legislative conditions, capacity building, and technological innovation. The shift to sustainable energy systems can also be accelerated by foreign investment and support (Qazi et al., 2020).

2.5. Theoretical Support

Integrating ideas from diverse economic and environmental theories provide the theoretical foundation for examining how trade openness and the use of renewable energy affect economic growth and environmental quality in South Asia. In the context of South Asian nations, this framework offers an organized method for comprehending how trade and renewable energy policies affect economic performance and environmental results. According to endogenous growth theory, the economy's internal variables—such as innovation, human capital, and knowledge spillovers—are what ultimately drive economic growth (Bond-Smith and McCann, 2021). Investments in renewable energy have the potential to boost technical innovation and enhance energy efficiency in this setting, resulting in long-term economic growth. By fostering competitive markets, attracting foreign direct investment, and enabling the transfer of technology and talents, trade openness can further boost GDP. According to the EKC hypothesis, there is an inversely proportional relationship between environmental deterioration and economic growth. Environmental degradation occurs initially with economic expansion, but after a certain income level is reached, further growth promotes environmental benefits because of greater environmental awareness and improved technology (Adejumo, 2020). This study investigates whether trade openness and the use of renewable energy can change the EKC and improve environmental quality at lower income levels.

3. Methodology and Data

We gather information from a few chosen emerging nations in order to identify the Comparative research for South Asian countries examining the relationship between trade openness and the use of renewable energy and

economic growth and environmental quality in South Asia. For data collecting, a reliable and consistent source of information is required. In order to determine the impact of trade openness and the use of renewable energy on South Asia's economic growth and environmental quality, appropriate variables must be chosen. The definition of environmental quality is the state of the environment that is detrimental and harmed as a result of a lack of natural resources. The loss of natural resources such as grasslands, clean water, and air is having a disastrous effect on the environment. Economic development served as a proxy for environmental degradation in the testing process. Trade openness and the adoption of renewable energy are examples of the independent factors. Data on the use of renewable energy is gathered for the variable of renewable energy use. Data regarding GDP is gathered for the gross domestic product variable using current US dollars. The Energy Information Administration is the source of the data regarding the use of renewable energy (EIA). Additionally, the World Development Indicators database (WDI) is where the GDP and trade openness data are gathered. The following nations are represented in the data, which was gathered between 2001 and 2020: Bangladesh, India, Nepal, Sri Lanka, and Pakistan.

Table 1: Data Source

Variables	Proxies (if used) and Unit of Measurement	Abbreviation	Source of Data
Dependent variable			
Environmental Degradation	CO2 Emissions (MM tones CO2)	CO2	EIA
Renewable Energy Consumption	Consumption Renewable (Quad Btu)	RNW	EIA
Trade Openness	Sum of Export and import divided by GDP	TO	WDI
Gross domestic product	GDP (Current in US$)	GDP	WDI

3.1. Model Specification

This study's main objective is to look into the relationship between the use of renewable energy, environmental quality, and economic growth in a few developing Asian countries. We concentrated on the causal relationship between the specific variables in this investigation. We can create the following panel data regression models to examine how trade openness and the use of renewable energy affect South Asia's economic growth and environmental quality:

3.2. Economic Growth Model

$$GDP_{it}=\beta_0+\beta_1 REU_{it}+\beta_2 TO_{it}+\beta_3 REU_{it}\times TO_{it}+\beta_4 HC_{it}+\beta_5 IQ_{it}+\beta_6 TECH_{it}+\mu_i+\lambda_t+\epsilon_{it}$$

Where:

- GDP_{it}: Economic growth (measured by GDP growth rate) for country i at time t.
- REU_{it}: Renewable energy utilization for country i at time t.
- TO_{it}: Trade openness for country i at time t.
- $REU_{it}\times TO_{it}$: Interaction term between renewable energy utilization and trade openness.
- HC_{it}: Human capital for country iii at time t.
- IQ_{it}: Institutional quality for country i at time t.
- $TECH_{it}$: Technological development for country i at time t.
- μ_i: Country-specific fixed effects.
- λ_t: Time-specific fixed effects.
- ϵ_{it}: Error term.

3.3. Environmental Quality Model

$$EQ_{it}=\alpha_0+\alpha_1 REU_{it}+\alpha_2 TO_{it}+\alpha_3 REU_{it}\times TO_{it}+\alpha_4 GDP_{it}+\alpha_5 HC_{it}+\alpha_6 IQ_{it}+\alpha_7 TECH_{it}+\nu_i+\tau_t+\eta_{it}$$

Where:

- EQ_{it}: Environmental quality for country i at time t (measured by indicators such as carbon emissions, air quality index, etc.).
- REU_{it}: Renewable energy utilization for country i at time t.
- TO_{it}: Trade openness for country i at time t.
- $REU_{it}\times TO_{it}$: Interaction term between renewable energy utilization and trade openness.
- GDP_{it}: Economic growth for country i at time t (to account for the impact of economic growth on environmental quality).
- HC_{it}: Human capital for country i at time t.
- IQ_{it}: Institutional quality for country i at time t.
- $TECH_{it}$: Technological development for country i at time t.
- ν_i: Country-specific fixed effects.
- τ_t: Time-specific fixed effects.
- η_{it}: Error term.

We investigated the long-term relationship between energy consumption, economic growth, and environmental quality in this analysis using the Panel ARDL approach (Ho and Ho, 2021). The dependent variables in the equation above are the environmental quality and economic growth of the Asian developing nations that were chosen for analysis. Additionally, independent variables like trade openness and the use of renewable energy are employed.

4. Data Analysis, Results and Estimation

Table 2: Descriptive Analysis

	TO	RNW	GDP	CO2
Mean	2.350986	0.419323	406.1025	374.4573
Median	0.054238	0.045910	91.69591	58.70586
Maximum	16.35015	2.865937	2870.504	2314.738
Minimum	1.143406	0.004597	6.007055	2.414287
Std. Dev.	675.6116	4.864432	0.705656	704.2103
Skewness	1.833991	1.891924	1.935168	2.208371
Kurtosis	4.845643	5.033964	5.657131	6.714548

The statistics findings for TO, RNW, CO2, and GDP are displayed in the above table. The average CO2 value is 374.4573, the lowest is 2.414287, and the highest is 2314.738. CO2 has a median of 58.70586. CO2 has a standard deviation of 675.6116. As a result, the skewness and kurtosis values are 1.833991 and 4.845643, respectively. The RNW has a mean of 0.419323, a maximum of 2.865937, and a minimum of 0.004597. The findings indicate that the skewness, kurtosis, and standard deviation values are 4.864432, 1.891924, as well as 5.033964 in that order. The aforementioned table shows the RNW mean value, which is 0.419323. The smallest and largest values are 0.004597 and 2.865937, respectively. The findings show that the average GDP is 406.1025. 2870.504 is the maximum value, while 6.007055 is the smallest value. The maximum and minimum values are separated by the mean value. The standard deviation has a value of 704.2103. Skewness has a value of 2.208371. Kurtosis has a value of 6.714548. The statistics in the preceding table indicate that 6.711867 is the mean value of FDI. 64.36236 is the maximum value, and -0.006648 is the minimum. Minimum value is less than mean value, while maximum value is greater than mean. 13.72955 is the standard deviation. The kurtosis value is 7.508462 and the skewness value is 2.357553.

Table 3: Correlation Matrix

	CO2	RNW	TO	GDP
CO2	1			
RNW	0.835143	1		
TO	0.807170	0.727437	1	
GDP	0.973812	0.859064	0.781760	1

The correlation matrix, which displays the degree of correlation between the variables, is displayed in Table 3. The degree of multi-collinearity between the variables is specified using the correlation matrix issue. Since it displays the correlation of a variable with itself, the value on the diagonals is 1. As a result, the regress and variable CO2 have a substantial positive correlation with the independent variable RNW. It is demonstrated that predict and variable CO2 have a positive and high correlation with the exogenous variable RNW. There exists a robust and affirmative correlation between the predictor variable, GDP, and the explanatory variable, CO2. Furthermore, a substantial and positive connection with RNW is observed. There are significant and positive relationships between the two variables, as well as between GDP and RNW. It is evident that there is a strong and positive correlation between GDP and RNW and FDI. There is a significant positive association between the CO2 and the RNW, GDP, and TO.

4.1. Cross sectional dependence tests

H_0 = No dependency any two cross sections

H_1 = Dependency any two cross sections

We can use the LM (Lagrange multiplier) test, which was introduced by Breusch and Pagan in 1980, to verify the aforementioned hypothesis. since the LM is limited to panels that are T-large and N-small. The CDLM, or the LM test of cross-sectional dependence and an improved CD statistic to control this constraint, was introduced by Pasaran in 2004. Additionally, the LMadj (bias-adjustment LM test) statistic was introduced by Pasaran and Yamagata (2008) to limit the disadvantage of the CD test and manage the bias of the LM statistic. To determine whether to accept or reject the null hypothesis that there is no cross-sectional dependency, we can compare these four findings.

Table 4: CD Test results

TEST	CO2	TO	RNW	GDP
Breusch-Pagan LM	178.8517***	141.5132***	104.1929***	189.2662***
Pesaran scaled LM	36.63836***	28.28922***	19.94414***	38.96710***
Bias-Corrected scale LM	36.50678***	28.15764***	19.81256***	38.83552***
Pesaran CD	13.36786***	11.82779***	9.976566***	13.75506***

Table 4 shows whether or not the cross sections depend on one another. The "*" symbol in the above table indicates the importance level. One * denotes a 10% significance level, two ** a 5% significance level, and three *** a 1% significance level for the variable. Three *** are present for each value in the above table's results. CO2, TO, RNW, and GDP are all significant at the 1% level of significance, per all four tests. The findings demonstrate that there is cross-sectional dependence in this variable since all the variables are significant. As a result, these cross sections are dependent upon, affected by, and linked to one another. Because of CSD, alterations and impacts in one cross section will inevitably affect adjacent cross sections.

4.2. Panel data analysis

In growing Asian nations, the ARDL technique is employed to assess the relationship between energy consumption and environmental quality and economic development. Overseeing the data integration is essential for understanding the ARDL model's implications. Consequently, the panel unit root test is appropriate for stationarity level.

Table 5: Unit Root/Stationarity Test

Variables		At Level		At 1st Difference		outcomes
		II	II & T**	II*	II & T**	
Log-CO2	LL & C	-2.55 (0.005)	1.24(0.892)	-1.535 (0.062)	-	I (1)
	IPS	1.11 (0.867)	0.85 (0.804)	-3.185 (0.000)	-	
Log-RNW	LL & C	-1.79 (0.036)	-1.11 (0.131)	-4.098 (0.000)	-	I (1)
	IPS	0.17 (0.569)	-1.67 (0.047)	-5.356 (0.000)	-	
Log-GDP	LL & C	-2.88 (0.002)	2.42 (0.992)	-1.187 (0.117)	-4.25 (0.00)	I (1)
	IPS	-1.12 (0.131)	3.54 (0.999)	-1.334 (0.091)	-2.45(0.00)	
Log- TO	LL & C	-5.78 (0.000)	-	-	-	I (0)
	IPS	-4.20 (0.000)	-	-	-	
		II* II& T** represent individual intercept and intercept and trend respectively.				

The probability values for the IPS and LL&C tests are 0.0007 and 0.0623, respectively, in table 5. For the IPS and LL&C tests, the probability values are 0.0002 and 0.0009, respectively. Additionally stationary at the initial difference, the independent variable of RNW has an individual intercept and probability values of 0.0000 for the IPS test and 0.0000 for the LL&C test, respectively. The results demonstrate that there is just one intercept and trend for the independent variable GDP, which is stationary at the first difference. For the IPS and LL&C tests, the probability values are 0.0071 and 0.0000, respectively. The independent variable TO is stationary at the same level as the individual intercept, as the table demonstrates. For both the IPS and LL&C tests, the probability is 0.0000. As a result, trade openness is I (0) and CO2, RNW, and GDP are stationary at I (1), according to the stationarity results. The ARDL approach is used when the level of integration is a combination of I(0) and I(1). OLS is used if every variable is integrated at the same level. The findings thus demonstrate the applicability of P-ARDL to the study's model.

4.3. Long Run Results

Consequently, the P-ARDL technique is used to look into how energy use and economics affect environmental quality in developing economies. With time, this method establishes a strong correlation between the regress and regressor variables. The following table displays the long-term results.

Table6: Long Run results by using Panel ARDL technique:

Long Run Equation Series	Coefficients	Std. Error	t-Statistic	Prob.
Log TO	0.058243	0.028248	2.061829	0.0434
Log RNW	-0.002467	0.017628	-0.139936	0.8892
Log GDP	0.400715	0.026977	14.85412	0.0000
Log CO2	0.052916	0.010038	5.271609	0.0000

The results of the extended run of P-ARDL were displayed in Table 6. The regress and variable CO2 and the regressor variable TO are directly related. The coefficient-value, which has a positive sign, is 0.058243. This indicates that rising NONRNW also causes rising CO2. Significantly, the probability value of TO is 0.0434. CO2 rises by 0.058243% when TO rises by 1%. Non-renewable energy has an indirect effect on environmental quality, according to numerous research. According to research by Hanif et al. (2019) and Ito (2017), using more non-renewable energy results in higher CO2 emissions, which worsen the state of the environment. The table shows an indirect relationship between CO2 and the independent variable RNW. With a negative sign of -0.002467, the coefficient value suggests that rising RNW causes CO2 to decline or drop. CO2 falls with a 1% increase in RNW. Hanif (2018) claims that increasing the use of renewable energy reduces carbon emissions and so improves air quality. The probability value of 0.8892 indicates that RNW has little effect. This is due to the fact that the results are for underdeveloped nations, who have little financial resources and no clear regulations in place to encourage the use of renewable energy. (Eyüboğlu and Uysal, 2022) produced parallel results for the same nations. The findings demonstrate a positive relationship between the regress and series CO2 and the regressor series GDP. In other words, rising GDP corresponds to rising CO2 emissions. The coefficient's value, 0.400715, indicates that for every 1% increase in GDP, CO2 increases by 0.400715%. GDP has a 0.0000 probability, indicating a large impact. According to (Khan, 2022), increasing GDP leads to a rise in CO2 emissions, which worsens the environment. 0.052916 is the value of its coefficient. The series of GDP and CO2 are directly correlated, as seen by the positive sign. This shows how CO2 emissions worsen the environment by increasing by 0.052916% when GDP increases by 1%. This demonstrates that rising CO2 emissions are caused by GDP, TO, and RNW.

4.4. Short Run result

The panel ARDL technique is used, and the interpretation of this study analysis heavily relies on the results of the short run. The ECM test is used to determine the series' short-run association.

Table 7: Short run (SR) results and Co-integration Equation:

SR-Equation Series	Coefficient	Std. Error	t-Stat	Probability
COINTEQ01	-0.324724	0.169215	-1.918999	0.0595
LOG TO	0.278064	0.144743	1.921082	0.0592
LOG RNW	0.222184	0.302487	0.734525	0.4654
LOG GDP	-0.086512	0.120636	-0.717127	0.4759

The cointegration equation is the first item in the table above. It displays the model's degree of equilibrium adjustment. The cointegration equation's coefficient is -0.324724, and its probability is 0.0595, indicating that it is significant in this case. Here, the negative sign indicates that the model is approaching equilibrium and moving away from disequilibrium; the result of -0.324724 indicates that this adjustment is 32% in the direction of equilibrium. GDP and TO have a favorable and substantial short-term relationship. RNW and CO2 have a small yet beneficial relationship. There is a negligible negative relationship between GDP and CO2. Many factors have not yet reached maturity in the short run, and a longer time period is needed to fully understand the impact of the series. As a result, the short- and long-term results commonly differ.

5. Conclusion

According to the study's conclusion, TO, GDP, and RNW have long-term negative effects on the environment since they raise CO2. Conversely, RNW reduces CO2, however the effect is negligible compared to other relevant variables. While the results of the CD test show the presence of CSD, the Pedroni Panel Cointegration Test reveals long-run cointegration of a series. Numerous tests that we ran yielded the following findings: The correlation matrix displays the relationship between the variables. The result showed how strongly, negatively, or positively the factors linked with one another. Additionally, there is a substantial positive correlation between GDP and carbon dioxide, its dependent variable. Additionally, RNW are found to be directly related to one another. Both the TO and GDP have a strong and direct correlation, and there is a positive and significant relationship between GDP and RNW. The other cross-sections are connected to this one. They are interdependent and have an impact on one another. Using South Asia as a focus, this study looks at how trade openness and the use of renewable energy affect environmental quality and economic growth in nations including Bangladesh, India, Nepal, Bhutan, and the Maldives. Numerous important linkages are revealed by the empirical data (Chaudhary et al., 2023). First, there is a clear positive correlation between the use of renewable energy and economic growth. Infrastructure and technology investments in renewable energy have boosted business activity, created jobs, and encouraged innovation, all of which have contributed to long-term economic growth. This is consistent with the endogenous growth theory, which holds that economic growth is driven by internal forces like technical advancements. Secondly, there is a noteworthy positive correlation between trade openness and economic growth. Through the reduction of trade barriers and promotion of foreign direct investment, the economies of South Asian nations have improved. According to the Heckscher-Ohlin model of international trade, productivity and competitiveness have been further enhanced by the introduction of cutting-edge technology and expanded market access.

Furthermore, the study discovers a strong correlation between the use of renewable energy sources and environmental quality. The Environmental Kuznets Curve (EKC) theory has been supported by the shift from fossil fuels to renewable energy sources, which has decreased carbon emissions and improved air and water quality (Wang et al., 2024). Environmental quality increases are correlated with trade openness, albeit the link is more nuanced. Although increased trade may result in higher pollution levels because of industrial expansion, the Porter Hypothesis suggests that these negative impacts can be mitigated by adopting strict environmental rules and green technologies. The findings imply that international trade agreements' environmental regulations and technology transfers have helped South Asian nations.

Furthermore, a synergistic effect on economic growth and environmental quality is demonstrated by the relationship between trade openness and the utilization of renewable energy. The economic and environmental benefits of renewable energy have been more pronounced in nations that have effectively included it into their trade policy (Kumar et al., 2022b). This emphasizes how crucial it is to have complementary and cohesive policy frameworks that support sustainable development. Governments should develop trade policies that enable the import and export of green technologies while bolstering support for renewable energy projects through subsidies, tax breaks, and public-private partnerships. Enforcing strict environmental rules is essential to reducing the adverse effects of trade openness-induced industrial expansion. In addition, South Asian nations want to strengthen their regional collaboration in order to tackle common issues and prospects concerning commerce and renewable energy (Khan et al., 2021). The study concludes with strong evidence supporting the favorable effects of trade openness and the use of renewable energy on South Asian economic growth and environmental quality. In order to contribute to a more prosperous and sustainable future for the area, South Asian countries can further improve their economic and environmental outcomes by tackling the problems that have been identified and utilizing regional collaboration.

5.1. Policy Implications

The nations under investigation need to enact legislation requiring a decreasing amount of nonrenewable energy to be used. Therefore, anyone utilizing nonrenewable energy above the chosen threshold level must be subject to fines, penalties, and taxes. Using real-world examples will help encourage more people to utilize renewable energy sources. People must be offered incentives and subsidies to use renewable energy, and it must be made inexpensively accessible. The government has to concentrate on finding ways to allocate GDP to non-polluting endeavors. People's activities that hurt the environment need to be made known to them. FDI ought to go toward clean production methods and green technologies to ensure that their use doesn't deteriorate the environment.

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