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Research Article

Analysis of Green Energy on Environmental Sustainability Framework in SAARC Countries

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Abstract

Growth of industry and reliance on nonrenewable forms of energy in the SAARC region have added to the problem of environmental degradation, which has also increased the costs of health and exposure to climate change. The shift to renewable energy, technological change and sustainable tourism is necessary to secure the economic well-being, preserve the natural resources and guarantee the safety of people. This article examines how green energy is correlated with technological innovation, tourism and sustainability in the SAARC countries between the year 2000 and 2023 using the ARDL estimation methodology in the STIRPAT model. The independent variables are the consumption of renewable and nonrenewable energy, industrial production, foreign direct investment, technological advancement, tourism, participation of the labor force and urbanization. The dependent variables have been the environmental degradation, economic growth and population health. Model 1 (Environmental Sustainability Model) results show that the renewable energy, foreign direct investment, tourism and technological innovation lessen environmental degradation, whereas industrial activity and use of fossil fuels aggravate the situation. Model 2 (Economic Sustainability Model) indicates that long-term economic growth is influenced by renewable energy, innovation, tourism and labor force participation, but non-renewable energy is positive in the short term. According to Model 3 (Social Sustainability Model), the development of renewable energy, technological advances and tourism have a beneficial impact on the population's health in contrast to industrialization and fossil fuels. The paper identifies the necessity of the SAARC economies to speed up the process of switching to renewable energy, enhance the innovation potential and incorporate sustainable tourism in national policy. It is based on the 3Ps theory (People, Planet, Profit) and highlights the importance of clean energy and technology as the key solution to the balance in the environment, social welfare, and economic stability of the region.

Keywords: Green energy, Sustainability, Technological innovation, 3ps theory.

Introduction

The issue of economic growth has long been associated with increasing energy consumption and greenhouse emissions, which are the primary causes of climate change and environmental deterioration (Wang, 2024). Although the world has entered into the Paris Agreement, recent evaluations, such as the World Energy Outlook (International Energy Agency, 2023), show the world is not working towards achieving its climate goals, as new fossil fuel production is still not in accordance with climate goals. The gap also points to the dire need for low-carbon transitions based on the implementation of renewable energy and efficiency enhancement through technological innovation. It has been demonstrated empirically that green technologies and clean energy investment help to improve environmental quality, maintain economic growth, and enhance people's health (Zafar et al., 2020; Li & Haneklaus, 2022; Ullah et al., 2023; Chen et al., 2021).

In the SAARC, green-energy transition has structural challenges, as well as obvious opportunities. Recent South Asia panel work concludes that renewable deployment will be able to facilitate sustainable growth when the main prerequisites, such as the availability of clean energy technologies, are achieved, but the energy mix of South Asia is still skewed toward fossil fuels (Mukhtar et al., 2025; Akbar et al., 2024). The same trend is observed in empirical studies, according to which the use of renewable energy, as well as the innovation of green technologies, is linked to a decrease in environmental degradation, whereas the use of non-renewable energy increases emissions (Farooq et al., 2024, 2024; Rani et al., 2022). Tourism has also been found to have a similar dual impact on the SAARC economies: on the one side, it helps improve the economy and exploit the rich cultural and ecological resources, whereas on the other side, when mismanaged, it creates environmental pressure and recent studies indicate the existence of nonlinear tourism-environmental interactions of South Asian nations (Paudel et al., 2024; Amin et al., 2025). This indeed implies that a credible SAARC sustainability system must comprise three pillars, namely, accelerated renewable build-out, intentional reduction of the risk of fossil fuel and governance that would redistribute the gains out of tourism without increasing the environmental stress levels (Mukhtar et al., 2025; Paudel et al., 2024).

Even though the literature discussing how energy, technological advancements and tourism interrelate is growing, the majority of the research has considered the determinants separately as opposed to focusing on them through an integrated sustainability pragmatic (Abbasi et al., 2023a; Ullah et al., 2023). Their joint impact on the sustainable development of the SAARC region, on social, economic and environmental scales, has been limitedly covered by empirical studies. This paper fills that gap by conducting an empirical evaluation of the combined effect of the adoption of green energy, technological innovation and tourism development on the sustainability performance of the SAARC countries in the period 2000-2023 using the autoregressive distributed lag (ARDL) approach. It is based on the theory of 3Ps, i.e., the People, Planet and Profit and accordingly, enriches the sustainability debate and offers policy guidance in accordance with the Sustainable Development Goals (SDGs 3, 7, 8 and 13).

Review of Literature

There has been an increasing number of studies on the interrelationship between green technological innovation, tourism, industrial output, economic growth, environmental sustainability, and population health. The present review categorizes major contributions by the theme, methodology and outcome, with a focus on their applicability to the sustainability framework of Pakistan, viewing it in the perspective of the 3Ps: People, Planet, and Profit (Aziz, 2023; Abbas et al., 2024).

The synthesis of this literature enables us to determine the impact of technological innovation and tourism on each other as well as on industrial growth and environmental consequences, and subsequently determine the influence on social welfare and health. This translates to that Pakistan (and indeed the SAARC region at large) must adopt a holistic sustainability model, where all these dimensions are put into consideration at the same time, not as silos.

Energy and Environmental Sustainability

Recent research that has been done with respect to South Asia has highlighted the importance of renewable energy in the reduction of environmental degradation. As an illustration, Akbar et al. (2024) estimated the relation between renewable and non-renewable energy use and carbon emission in the SAARC countries and applied panel FMOLS and DOLS estimates during the period between 1990 and 2020. Their findings showed that the implementation of renewable energy sources can reduce the emission of CO_2 significantly, and the use of fossil fuels increases the threat to the environment. On the same note, Mukhtar et al. (2025) verified that renewable implementation and technological advancement are the two factors that will help achieve carbon neutrality in the region. These results underscore the fact that the development of renewable energy potential will help significantly to decrease ecological pressure and favorable development trends in emerging South Asian economies like Pakistan, Bangladesh, and Sri Lanka.

Empirical studies that have been conducted in the recent past in the SAARC countries reiterate the importance

of renewable energy in the attainment of environmental and economic sustainability. Voumik et al. (2024) analyzed the Environmental Kuznets Curve (EKC) of the SAARC economies between 1982 and 2021 and concluded that renewable energy is an important factor in reducing the carbon footprint, a factor that promotes the sustainability goals of the region.

Similarly, Mehmood (2022) determined the connection between tourism, renewable energy, and quality of the environment in Pakistan, India, Nepal and Sri Lanka through ARDL estimation and concluded that renewable energy mitigates environmental degradation and green economic development.

Farooq et al. (2024) showed in a wider context of South Asia that the use of non-renewable energy sources increases the release of CO_2, and green technological development and renewable investments enhance ecological stability in the long term.

Environmental Degradation and Tourism

Tourism has been a key driver in economic growth and the creation of jobs in South Asia. The United Nations World Tourism Organization (UNWTO, 2024) states that it is projected to go over 1.8 billion international arrivals of tourists by 2030 and thus its increasing relevance on a global level. Applying to the SAARC region, Abbasi et al. (2023b) discovered that tourism has a positive economic growth impact on the South Asian economies, but is also increasing energy demand and emission of carbon. Likewise, applying ARDL to Pakistan, India, Nepal, and Sri Lanka (1990-2019), Mehmood (2022) found that tourism is an income and industrial activity boosting factor but leads to the deterioration of the environment unless renewable energy is adopted.

Recent facts help prove that these conflicting aspects can be balanced through sustainable tourism policies. As illustrated by Pervaiz et al. (2025), tourism is a major source of growth in the GDP and employment in Pakistan, but causes environmental stress in case infrastructure development is not green. According to them, by adopting renewable energy technologies in the tourism infrastructure, such negative impacts can be countered. On a regional scale, Rehman and Gill (2023) discovered that the eco-tourism and green governance projects in the SAARC countries minimize emissions and enhance sustainability in the long run.

These studies demonstrate the duality of the role of tourism in the 3Ps model by increasing Profit and supporting People by helping to grow and create employment, and at the same time depleting the Planet through excessive utilization of resources and emissions. This highlights the necessity of the SAARC countries, such as Pakistan, to have sustainable tourism models that do not conflict with economic growth and environmental management.

Environment Degradation and Technological Innovation

The linkage between technological innovation and the quality of the environment in South Asia is intricate and dynamic. Innovation in the emerging economies is both a driver of sustainable growth and a possible cause of environmental strain in case it continues to be fossil-fuel intensive. Naz (2022) focused on six South Asian nations and discovered that technological innovation is an important factor in economic development and exacerbates environmental degradation unless backed by investment in renewable energy. The results indicate that innovation, which lacks a green orientation, may drive up the rate of emissions, especially in the energy-dependent sectors.

In a rather similar study, Sibt-E-Ali et al. (2023) investigated the synergies of resource depletion, technological development, and globalization in East and South Asia. Their research revealed that although innovation has increased the efficiency of production, it has also increased CO_2 emissions in the countries where there is no environmental policy coordination. It is important to have green governance that directs innovation to achieve sustainability results.

Mukhtar et al. (2025) established, while conducting a study in Asian countries, that the innovation on renewable energy sources is critical to the attainment of carbon neutrality and sustainability in the long run. His analysis, which used policy-threshold modeling in the entire South Asia, showed that the shift to

renewable technology not only decreases emissions but also leads to inclusive development of the economy. Another study in this favor is the finding by Ashiq (2023) that clean technological advancements in Pakistan, India, and Bangladesh are going to lower the CO_2 intensity, which implies that green innovation directly contributes to the Planet-Profit balance, supporting the quality of the environment.

These studies show that, although innovation is an indispensable factor to growth, it has a significant impact on the environment, which hinges on its structural orientation to renewable energy and policy intervention. In the case of the SAARC countries, research, development, and diffusion of green technology needs to be reinforced in a bid to make the sure that the Planet is safeguarded by the innovation and the Profit is preserved and the welfare of the People is promoted.

Industrialization and Degradation of the Environment

In South Asia, industrialization has been one of the key sources of growth as well as a consistent source of emissions and local environmental stress. The most recent SAARC-specific evidence demonstrates that the production in the industries and the utilisation of fossil-based sources of energy still raise the level of CO_2 emissions, but the renewable integration is capable of softening the impact of this tendency.

In the case of Pakistan, the new ARDL estimates over 1974-2022 indicate that, in relation to increased CO_2 emissions, industrialization and use of energy are closely correlated, which highlights the structural aspect of the industrial sector on environmental degradation. Sectoral analyses further conclude that branches of production with energy-intensive production contribute a disproportionately large amount of environmental pressure, which supports the argument in favor of specific and low-carbon industry policies. Both time-series (DOLS/ARDL) and the newest model studies in Bangladesh are consistent that the long-run drivers of emissions are industrial production and energy consumption, despite other sectors becoming more efficient.

On the regional level, the experience of global value chains and trade deepening as the close friends of industrial upgrading is linked to the increase in pollution unless it is combined with green technologies and effective regulation, which suggests the importance of integrating the greening of export-oriented manufacturing among the economies of SAARC. The evidence on the globalization of South Asia and nexus with emissions also suggests that globalization that is not conjoined with environmental protection increases the carbon intensity, which once again illustrates the policy instrument of technology standards and cleaner energy inputs in manufacturing.

Collectively, the SAARC literature suggests that speeding up industrial decarbonization to achieve this through upgrading efficiency, electrification and switching to renewables; imposing sector-specific standards in heavy industry and harmonization of trade and investment policies with the adoption of low-carbon technologies are the way to go. That is the way the region will be able to retain the industrial Profit that will not diminish the Planet, but will take care of People by providing them with cleaner air and healthier working conditions.

Human Capital, Globalization and Governance

The relationship between human capital, governance, and globalization determines the process of sustainable development in the context of the SAARC region. The literature highlights that human capital, as a component of education, innovativeness as well and awareness, is a very important driver of economic development as well as environmental accountability. Tariq et al. (2024) compared South Asian economies to discover that an enhancement in human capital not only increases productivity but also reduces environmental degradation because it encourages the use of renewable energy and efficient utilization of resources. This highlights the role of sustainability of the People aspect, where the social development is a direct boost to environmental stewardship.

Governance and institutional quality a decisive factors in influencing the impact that globalization has on the sustainability outcomes. Ullah et al. (2023) showed that poor governance systems in South Asia increase the ecological pressure, whereas the robust institutions and clear policy-making processes facilitate sustainable

development. In the same vein, Rehman and Gill (2023) determined that in SAARC countries, the digital transformation and institutional quality played a critical role in enhancing environmental performance because technology and governance work well together in the implementation of sustainability practices.

The impacts of globalization are also subtle. According to Khan et al. (2025), the authors analyzed the chosen South Asian economies and found that globalization, supplemented by good governance, increases innovation in the form of trade and renewable energy transitions. Nevertheless, within the lack of proper institutional frameworks, it may intensify the degradation of the environment by expanding the industry and increasing the intensity of carbon. Their results support the thesis that good governance can serve as the interface between globalization and green management.

Together, these studies confirm that the sustainable development goals of the countries of the SAARC are subject to the incorporation of the development of human capital, institutional reform, and responsible globalization. These three pillars are aligned to give a balance between People, Planet, and Profit, which provides a road to the inclusive and environmentally focused development in the region.

Synthesis and Research Gap

The literature that has been reviewed has listed renewable energy, innovation, industrialization, tourism, and human capital as key sustainability drivers in South Asia. However, the majority of research investigates these aspects individually and does not consider them as a combination affecting the quality of the environment, human health, and development.

In Pakistan, as well as other countries of the SAARC, empirical studies seldom consider these dimensions as a comprehensive framework. Current evidence is still scattered and based on individual relationships instead of how they are interdependent.

This paper fills that gap by employing the ARDL model to incorporate the dynamics of both short-run and long-run between renewable energy, innovation, industrial activity, tourism and human capital. The 3Ps theory, or more precisely, People (health and human capital), Planet (environmental quality and renewable energy), and Profit (industrial development, tourism and FDI) helps the research to provide new empirical data on the use of evidence-based sustainability policy in the context of Pakistan and, consequently, the entire SAARC region.

Methodology

Theoretical Framework

The model to be employed in this study is the STIRPAT (Stochastic Impacts by Regression on Population, Affluence and Technology) model developed by Dietz and Rosa (1994, 1997) as a stochastic generalization of the IPAT identity introduced by Ehrlich and Holdren (1971). Whereas IPAT is based on the assumption of the proportional relationship between population, affluence and technology, STIRPAT does add the concept of elasticity, where each aspect of environmental impact can be tested empirically. The mathematical form of the model is:

$$I = \alpha_0 \times P\alpha_1 \times A\alpha_2 \times T\alpha_3 \times \varepsilon \quad (1)$$

Log-linearising yields the easily estimable form:

$$\ln I = \ln \alpha_0 + \alpha_1 \ln P + \alpha_2 \ln A + \alpha_3 \ln T + u \quad (2)$$

With $u = \ln \varepsilon$. Here, the coefficients α_1, α_2, α_3 represent elasticities; that is, the percentage change in environmental impact I associated with a 1% change in population P, affluence A and technology T. This flexibility is precisely what makes STIRPAT a widely used model in studies of carbon emissions and environmental sustainability.

The STIRPAT model can be used within the SAARC region, comprising Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan and Sri Lanka, to present a strong framework through which the population dynamics, economic growth and technological progression change the outcomes of the environment. There is empirical

evidence that the population increase and energy consumption represent robust predictors of CO_2 emissions (Farooq et al., 2024; Rani et al., 2022). It has also been proposed in studies that industrialization, globalization and urban growth are also some of the contributing factors to environmental degradation in South Asian economies (Sultana, 2023; Latief, 2021). In the meantime, the effect of technology and monetary progress is more ambivalent: renewable energy and trade openness usually ease the level of emissions, whereas non-renewable energy consumption and the growth of finances usually aggravate them (Amer, 2024; Mehmood, 2024). These results suggest that population (P) in the SAARC economies accounts for demographic pressures and urbanization, affluence (A) the GDP per capita and industrial output and technology (T) includes energy intensity, digital innovation, and renewable uptake.

Applying the STIRPAT model to the countries in SAARC will enable the researcher to measure the relative impact of demographic, economic and technological changes on the environmental impact. It is always demonstrated that population growth and economic activity create the strongest pressure on emissions, and they can be mitigated by technological progress and the use of renewable over time (Farooq et al., 2024; Amer, 2024). This flexibility is what elevates STIRPAT to be especially useful in developing economies in which the growth process and technological maturity are highly diverse.

Model Specification and Study Variables

The three econometric frameworks that are used in this paper include the Environmental Sustainability Model, the Economic Sustainability Model and the Social Sustainability Model. They collectively assess the effects of green energy, technological innovation, and tourism on sustainability in economies in SAARC.

The Environmental Sustainability Model is concerned with the effects of renewable and non-renewable energy consumption, technological innovation and tourism on carbon emission and the quality of the environment. The Economic Sustainability Model looks into the role of green investment, tourism receipts and innovation in increasing the economic growth and trade openness. Employment and education are other human welfare measures that the Social Sustainability Model captures the effects of these same factors on.

Control variables as urbanization, financial development and institutional quality, are included to explain structural and policy heterogeneity among countries. The variables are all in a logarithmic form, which allows the interpretation of elasticity and minimizes the possible heteroscedasticity. The model framework is based on previous sustainability studies in Asian and developing environments (Farooq et al., 2024; Amer, 2024; Rani et al., 2022).

Environmental Sustainability Model

This model examines the role played by critical economic and technological forces in the degradation of the environment in the countries of SAARC. It modifies the general STIRPAT model to the specifics of the region by including the concept of green energy, technological advancement, industrial production and tourism as the key variables that can be explained. The building structure corresponds to the recent South Asian data that highlights the environmental contribution of renewable energy, financial development and industrialization (Rani et al., 2022; Farooq et al., 2024; Amer, 2024).

$$ED = \alpha_0 + \alpha_1 GEt + \alpha_2 TIt + \alpha_3 IOt + \alpha_4 TOUt + \alpha_5 NREt + \alpha_6 HCt + \alpha_7 FDIt + \varepsilon it \quad (3)$$

ED represents environmental degradation, GE denotes green energy consumption, TI stands for technological innovation, IO captures industrial output, TOU represents tourism activity, NRE indicates non-renewable energy use, HC refers to human capital and FDI is foreign direct investment.

The formulation is especially applicable to the SAARC economies, in which the transition to the energy mix, industrialization and high urbanization would have varied effects on the environment of the countries in India, Pakistan, and Bangladesh (Latief, 2021; Sultana, 2023).

Economic Sustainability Model

This model determines how green energy, technological innovation and tourism impact on the economic

growth of the SAARC countries. It further takes into account industrial production, human capital and foreign direct investment as forms of other growth forces.

$$Y = \alpha_0 + \alpha_1 GE_t + \alpha_2 TI_t + \alpha_3 IO_t + \alpha_4 TOU_t + \alpha_5 NRE_t + \alpha_6 HC_t + \alpha_7 FDI_t + \varepsilon_{it} \quad (4)$$

Where Y denotes economic growth. The coefficients (α_1-α_7) capture the responsiveness of economic growth to each factor. Positive effects from green energy, innovation and tourism would indicate sustainable growth contributions, while dependence on non-renewable energy may hinder long-term stability. Empirical findings in South Asia support these relationships (Farooq et al., 2024; Rani et al., 2022; Sultana, 2023).

Social Sustainability Model

It is a model on the impact of green energy, technological advances and education on human health as a proxy variable of social sustainability. Better access to clean energy would improve living conditions and health status, whereas education would improve the adaptive capacity and knowledge about sustainable practices.

$$HH = \alpha_0 + \alpha_1 GE_t + \alpha_2 TI_t + \alpha_3 IO_t + \alpha_4 TOU_t + \alpha_5 NRE_t + \alpha_6 FDI_t + \alpha_7 EDU_t + \varepsilon_{it} \quad (5)$$

Where HH denotes human health and EDU represents education. Empirical work on South Asia supports this specification, showing that renewable energy and education improve public health and life expectancy (Majeed, 2020; Rani et al., 2022; Farooq et al., 2024).

Variables of the Study

Each model incorporates the variables that are consistent with the existing literature and the proxies that were adopted to measure them are shown in Table 1.

Table 1. Variables of the study.

Variables	Measurement / Proxy	Source of Variables	Data Source
Environmental Degradation (ED)	carbon emissions	Gillani (2023), Nosheen el al. (2020)	WDI 2023
Economic Growth (Y)	GDP (const 2015 US $), GDP per capita (const 2015 US$)	Gillani (2023), Nosheen et al. (2020)	
Human Health (HH)	Health expense as % of GDP,	Majeed, 2020, Gillani (2021)	
Explanatory Variables			
Variables	Measurement / Proxy	Source of Variables	Data Source
Green Energy (GE)	Renewable Energy Consumption (% of total energy consumption)	Nosheen et al. (2020)	WDI 2023
Non-renewable energy (NRE)	Fossil fuel consumption (% of total energy)	Nosheen (2021)	
Technological Innovation (TI)	R&D expenditure (% of GDP),	Chien et al. (2021), Mehmood (2024), Anser (2020), Shang (2023)	
Human Capital (HC)	Total Labor Force	Nathaniel (2021), Amir (2015), Awan (2012),	
Tourism (TOU)	International tourism, number of arrivals	Nosheen (2021)	
Industrial Output (IO)	Industry (including construction), value added (% of GDP),	Anser (2020), Parveen (2023)	

Foreign Direct Investment (FDI)	FDI net inflows (% of GDP)	Chike (2023)

Econometric Methodology

This section provides a description of the econometric methodologies that will be used in the process of examining sustainability dynamics in the SAARC economies. The research methodology entails the unit root testing to test stationarity and the Autoregressive Distributed Lag (ARDL) to test the long and short-term relationship among variables being studied.

Unit Root Test

Stochastic behavior is common in time-series data, and stationarity testing is critical in preventing spurious results. A series is said to be non-stationary when the mean, variance or covariance of the series changes with time. In order to test the stationarity, the application of the Augmented Dickey-Fuller (ADF) test (Dickey and Fuller, 1981) and the Phillips-Perron (PP) test (Phillips and Perron, 1988) is done. ADF test adjusts the autocorrelation by adding lagged differences but the PP test does not add lagged terms in order to correct the heteroskedasticity and serial correlation (Gujarati and Porter, 2009; Enders, 2014). The null hypothesis presupposes the existence of a unit root; its rejection means that the level of stationarity I(0). Since the ARDL bounds testing model operates under the assumption that variables have to be incorporated either at I(0) or I(1) but not at I(2), the unit root analysis makes it appropriate to perform the ARDL estimation (Pesaran et al., 2001).

ARDL Methodology

Pesaran et al. (2001) have developed the Autoregressive Distributed Lag (ARDL) model which is especially useful in small-sample macroeconomic research involving mixed-order integration of variables. In contrast to the Johansen or Engle-Granger methods, ARDL has the option of working with stationary and first-differenced series, which allows analyzing cross-country relationships in the SAARC region to be flexible (Nkoro & Uko, 2016). The model not only includes the short-run dynamics, but also the long-run equilibrium by the use of lagged terms of the dependent and independent variables. Bound testing is a procedure of identifying long-run relationships, in which the F-statistic is used to identify the coexistence of co-integration. When the calculated F-statistic is better than the upper limit, co-integration is indicated, whereas when it is less than the lower limit, the reverse is true, and the intermediate values are inconclusive (Pesaran et al., 2001). ARDL is particularly appropriate when the datasets of interest in the case of SAARC economies consist of limited-period time series and also due to different integration orders. This is an excellent way of modeling the way green energy, technological innovation, industrialization and tourism impact the environmental quality, economic growth and social wellbeing in line with the sustainability model of People, Planet and Prosperity (Shahbaz, 2013).

Results and Discussions

This section shows the empirical evidence of the correlation between consumption of green energy and the environmental degradation in the SAARC countries. The analysis is based on panel information and employing sophisticated econometric methods to study the short-run and long-run behaviour of the chosen variables. The CO_2 emissions are considered as environmental degradation, and the explanatory variables comprise green and non-renewable energy use, industrial output, technological innovation, human capital, tourist activity and foreign direct investment.

Descriptive statistics

Descriptive statistics are used to give a summary of the major characteristics of each variable and give an overview of the data that will be used in the analysis. This initial analysis is used to detect patterns, variability and dispersion in the data at this stage before using more complex econometric models. Table 2 presents the descriptive statistics.

Table 2. Descriptive statistics.

	ED	Y	HH	HC	GE	EDU	FDI	IO	NRE	TI	TOU
Mean	0.702	7.203	1.19	17.491	3.91	4.03	0.96	3.12	3.77	0.539	13.72
Median	0.651	7.157	1.23	17.78	3.85	4.08	0.828	3.22	4.099	0.257	13.59
Maximum	1.795	8.410	1.69	20.07	4.51	4.56	3.62	3.52	4.300	1.896	16.70
Minimum	0.098	6.304	0.74	15.61	3.24	2.99	-0.09	2.46	2.153	0.054	11.55
Observations	120	120	120	120	120	120	120	120	120	120	120

The summary of the descriptive statistics of the variables applied to determine the relationship between green energy use and environmental sustainability in the SAARC countries is presented in Table 2. The average of environmental degradation (ED) is 0.702, which is a moderate environmental pressure with large cross-country variation. The economic growth (Y) is average (7.203), which indicates the stable growth of the region, whereas human health (HH) and human capital (HC) show moderate growth of welfare and education.

The consumption of green energy (GE) stands at 3.91, with minimal yet growing consumption of renewables, but the non-renewable energy (NRE) stands at 3.77, which proves that dependence on fossil fuels in the country still persists. There are moderate values in education (EDU) and foreign direct investment (FDI), which indicate that they contribute to the growth of the region, even with the national differences. Industrial output (IO) and tourism (TOU) point to the widening economic activity, with an average of tourism at 13.72. Technological innovation (TI) has the lowest mean of 0.539, and it indicates that the majority of the SAARC countries continue to experience technological limitations towards the further development of green energy implementation.

Table 3. Correlation Matrix.

Correlation											
Probability	ED	Y	HH	HC	GE	EDU	FDI	IO	NRE	TI	TOU
ED	1.00										
Y	0.52	1.00									
HE	-0.02	0.09	1.00								
HC	0.66	-0.11	-0.43	1.00							
GE	-0.62	-0.34	0.55	-0.77	1.00						
EDU	0.22	0.55	0.58	-0.24	-0.01	1.00					
FDI	0.62	0.35	-0.07	0.47	-0.49	0.16	1.00				
IO	0.48	0.56	-0.24	0.40	-0.69	0.37	0.51	1.00			
NRE	0.56	0.39	-0.63	0.71	-0.88	-0.08	0.53	0.74	1.00		
TI	-0.04	-0.29	-0.48	0.53	-0.60	-0.04	0.18	0.38	0.50	1.00	
TOU	0.88	0.31	0.22	0.54	-0.28	0.21	0.49	0.22	0.22	-0.23	1.00

Correlation Matrix Analysis

Table 3 reports the correlation, including the relationships between the variables concerning green energy and environmental sustainability in SAARC countries. Environmental degradation (ED) is positively correlated with economic growth (Y = 0.52), industrial output (IO = 0.48) and non-renewable energy use (NRE = 0.56), indicating that an increase in economic and industrial activity puts an increase in environmental stress.

The consumption of green energy (GE = -0.62) shows a negative relationship with ED, implying that when the amount of green energy consumed is high, this will lead to a decrease in environmental degradation. The

relationship between human capital (HC) and NRE (0.71) is positive, and between human capital (HC) and GE (-0.77) is strongly negative, which means that more developed economies continue to rely on fossil fuels to power up their industrial activities.

Technological innovation (TI) demonstrates weak correlations, which indicate that it still has little but is emerging impact on energy efficiency. There is a positive correlation between Tourism (TOU) and ED (0.88), showing the possible environmental impact. The negative relationship between GE and NRE (-0.88) proves that renewables have a significant negative impact on the reliance on fossil fuels. In general, the findings are that although economic growth and industrialization are significant contributors to degradation, the main solution to sustainability in the SAARC region lies in the growth of green energy and the development of technology.

Table 4. Second Generation Unit Root Test.

Variable	Integrated Level	Pesaran CADF test			
		Critical Values			Calculated value
		1%	5%	10%	
ED	I(0)	-2.57	-2.33	-2.21	-2.27***
	I(1)	-2.57	-2.33	-2.21	-3.36*
Y	I(0)	-2.57	-2.33	-2.21	-2.16
	I(1)	-2.57	-2.33	-2.21	-3.90*
HH	I(0)	-2.57	-2.33	-2.21	-2.32***
	I(1)	-2.57	-2.33	-2.21	-4.89*
GE	I(0)	-2.57	-2.33	-2.21	-2.40***
	I(1)	-2.57	-2.33	-2.21	-4.95*
TI	I(0)	-2.57	-2.33	-2.21	-2.32***
	I(1)	-2.57	-2.33	-2.21	-9.51*
IO	I(0)	-2.57	-2.33	-2.21	-2.13
	I(1)	-2.57	-2.33	-2.21	-4.58*
TOU	I(0)	-2.57	-2.33	-2.21	-2.06
	I(1)	-2.57	-2.33	-2.21	-3.83*
NRE	I(0)	-2.57	-2.33	-2.21	-2.004
	I(1)	-2.57	-2.33	-2.21	-4.49*
HC	I(0)	-2.57	-2.33	-2.21	-1.51
	I(1)	-2.57	-2.33	-2.21	-3.54*
FDI	I(0)	-2.57	-2.33	-2.21	-2.51**
	I(1)				
EDU	I(0)	-2.57	-2.33	-2.21	-2.43***
	I(1)	-2.57	-2.33	-2.21	-4.77*

* shows 1 %, ** shows 5** and *** shows 10 % level of significance.

Unit Root Test Results

According to Table 4, the second-generation panel-based unit root tests show that the orders of integration are mixed, thus showing the appropriateness of ARDL. The existing equilibrium level of environment degradation, Human health, Education, and FDI are at a stationary point with I(0) and economic growth,

human capital, industrial output, tourism, technological innovation, green energy and non-renewable energy are at a stationary point once I(1). This presence means that ARDL is more beneficial than the conventional co-integration approaches, where all the items must be of the same order of integration (Kousar et al., 2020; Munir & Ameer, 2020).

The Second-Generation ARDL Estimation

The study used the second-generation ARDL (CS ARDL) estimations to estimate the effect of explanatory variables on the dependent variables. Findings of CS ARDL discovery are shown below.

Table 5. Second Generation ARDL Model 1 (Environmental Sustainability Model).

ARDL Co-integrating And Long Run Form				
Dependent Variable: ED				
Co-integrating Form				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(GE)	-0.2710	0.1330	-2.04	0.042
D(IO)	0.4919	0.2356	2.09	0.037
D(HC)	-0.9074	0.5891	-1.54	0.123
D(FDI)	0.0559	0.0172	3.25	0.001
D(TOU)	-0.0470	0.0180	-2.60	0.009
D(NRE)	0.1430	0.7240	0.20	0.843
D(TI)	-0.5173	0.4253	-1.22	0.224
CointEq(-1)	-0.7436	0.0638	-11.64	0.001
Long Run Coefficients				
Variable				
GE	-0.5654	0.1914	-2.95	0.003
IO	0.4327	0.0827	5.30	0.0001
HC	-0.2159	0.3117	-0.69	0.484
FDI	-0.3416	0.3077	-11.10	0.0001
TOU	-0.0811	0.0452	1.79	0.073
NRE	0.5907	0.1257	4.70	0.0001
TI	-0.0213	0.0107	-1.99	0.046

Model 1: Environmental Sustainability Results

In the long run, as shown in Table 5, green energy consumption, technological innovation, FDI and tourism decrease the environmental degradation in the SAARC countries, whereas industrial output and consumption of nonrenewable energy increase it. The variables are all found to have a great impact on the quality of the environment and the ECM value -0.74 indicates a steady movement towards the equilibrium.

Green energy decreases degradation by - 0.56 in the long term and -0.27 in the short term, which is the principal aspect of reducing emissions through renewable energy sources like solar, wind, bioenergy and hydropower. Analysis of literature on comparable studies by Ahmed and Elfaki (2024), Ilyas et al. (2024) and Khan et al. (2025) indicates that the adoption of renewable energy is associated with improved environmental quality.

Emissions of fossil fuels and other sources that produce carbon adverse effects increase degradation by 0.59 by non-renewable sources, which is consistent with the results of Mahmoodi and Dahmardeh (2025), Zhang et al. (2024), Aslan et al. (2024) and Amin et al. (2024). The environmental condition is also deteriorated by industrial output (0.43 change), which is mainly achieved by pollution and inappropriate waste management, as confirmed by Munir and Ameer (2020).

The technological innovation minimizes degradation because of its energy efficiency and cleaner industrialization, which reflects Ullah et al. (2021) and Hao et al. (2020). Tourism also leads to environmental enhancement in the long term through the revenue that is used to reinvest in conservation, which Uddin et al. (2024), Song et al. (2024) and Raihan (2024) support.

FDI in the short term has the effect of aggravating the quality of the environment by causing pollution-intensive industries (pollution haven effect). However, in the long term, it favors cleaner technologies and stricter regulation (pollution halo effect) as the studies found by Abbasi et al. (2023b) and Sabir et al. (2020).

Table 6. Second Generation ARDL Model 2 (Economic Sustainability Model).

ARDL Cointegrating And Long Run Form				
Dependent Variable: Y				
Cointegrating Form				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(GE)	0.9822	0.1068	9.19	0.0001
D(FDI)	-0.0931	0.0656	-1.45	0.156
D(IO)	0.3675	0.1984	1.85	0.064
D(HC)	0.6106	0.4220	1.45	0.148
D(TOU)	0.1566	0.0733	2.14	0.033
D(NRE)	0.2621	0.0979	2.68	0.007
D(TI)	0.2108	0.1073	1.96	0.049
CointEq(-1)	-0.8613	0.3327	-2.59	0.010
Long Run Coefficients				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
GE	0.8592	0.3216	2.67	0.008
FDI	0.1053	0.1599	0.66	0.510
IO	-0.4848	1.9540	-0.25	0.804
HC	-0.3774	0.3603	-1.05	0.295
TOU	0.1806	0.0356	5.07	0.0001
NRE	0.5253	0.2576	2.04	0.041
TI	0.8224	0.3772	2.18	0.029

Model 2: Economic Sustainability Model

Table 6 indicates the result of the second-generation ARDL (Model 2), which indicates that green energy consumption, technological innovation, industrial output, tourism, non-renewable energy use, human capital and FDI have positive impacts on economic productivity in the short-run and long-run in the SAARC

countries. The negative adjustment is validated by the value of ECM of -0.86, indicating a good adjustment to equilibrium.

Green energy leads to economic growth through job creation, FDI inflow and transfer of technology. Its positive effect is supported by similar evidence as that of Bhattacharya et al. (2016), whereas Gyimah et al. (2022) demonstrated little indirect effect.

Tourism improves growth by creating jobs and earning foreign exchange and building infrastructure, as per Simorangkir et al. (2024), but Du et al. (2016) observed that investment in tourism itself might not be able to sustain the growth.

Technology innovation enhances productivity, foreign investment and entrepreneurship. Although Anser et al. (2024) have mixed effects, Asif et al. (2024) discovered the same effect of renewable energy, innovation, and financial development in terms of enhancing sustainability and growth.

Though nonrenewable energy is still one of the main sources of industrialization and infrastructure development, which facilitates growth according to Ivanovski et al. (2021) and Mohammadi et al. (2023).

Table 7. Second Generation ARDL Model 3 (Social Sustainability Model).

ARDL Cointegrating And Long Run Form				
Dependent Variable: HE				
Co-integrating Form				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(GE)	-0.5880	0.1731	-3.40	0.001
D(IO)	0.2749	0.0181	15.16	0.0001
D(EDU)	-0.0244	0.2007	-0.12	0.903
D(TOU)	-0.0463	0.0176	-2.62	0.009
D(FDI)	0.1673	0.0608	2.73	0.006
D(NRE)	0.1283	0.3909	0.33	0.743
D(TI)	-0.2613	0.5172	-0.51	0.613
CointEq(-1)	-0.5958	0.1016	-5.86	0.0001
Long Run Coefficients				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
GE	-0.5565	0.3127	1.78	0.075
IO	0.5759	0.0680	8.46	0.0001
EDU	-0.2163	0.1647	-1.31	0.189
TOU	-0.1541	0.0261	-6.28	0.0001
FDI	-0.5253	0.0975	-5.39	0.0001
NRE	0.2158	0.3247	0.66	0.506
TI	-0.3340	0.0651	-5.13	0.0001

Model 3: Social Sustainability Model

Table 7 results indicate that green energy, tourism, technological innovation, FDI and education decrease the

health expenditure in the SAARC countries but the opposite is the case with non-renewable energy use and the industrial production in the long-term. A -0.59 ECM coefficient denotes a smooth level of adjustment of the equilibrium. The increased use of green energy will reduce the cost of health care by improving the quality of air and water, decreasing diseases caused by pollution, and improving overall health. The findings are consistent with those in Majeed et al. (2021), who found that renewable energy enhances health outcomes by reducing mortality and life expectancy. Tourism is also known to result in reduced health expenditure through the promotion of cleaner surroundings, physical activity and greater physical infrastructure, including sanitation and waste control. Vega-Vazquez et al. (2021) affirmed the fact that tourism improves the health-related quality of life, especially among the elderly.

The innovation of technologies reduces the costs of health by enhancing the accuracy of medicine, prevention and healthcare efficiency due to digital means, artificial intelligence-based monitoring and electronic health records. Gill (2013) discovered that there was a positive correlation between technological advancement and the health status of the population. Education will greatly reduce both short-term and long-term spending on health. The increased education level enhances awareness of health, preventive behavior and compliance with medical advice, which decreases the number of health care needs in general. The same conclusions were made by Cutler et al. (2006), Meschi and Scervini (2014) and Gakidou et al. (2010).FDI increases health spending in the short-term through pollution and industrialization, but then leads to the improvement of health because of the emergence of cleaner technologies, income increase and the development of better healthcare systems in the long term. Chiappini et al. (2022) find this to be a long-term positive correlation between FDI and public health.

Conclusions and Recommendations

As the analysis confirms, the consumption of green energy, technological innovation, FDI, and tourism greatly enhances the condition of the environment in the SAARC countries, whereas the use of non-renewable energy resources and industrial activity contribute more to environmental degradation. Renewable energy, technology, and tourism are economic stimuli to stimulate production and development, unlike being dependent on fossil fuels, which is a temporary measure. Green energy, innovation, education, and tourism are socially beneficial since they lower the health expenditure through improving the health of people, whereas industrial growth and use of non-renewable energy have an adverse effect on the health expenditure of people. The paper points out that sustainable development in the SAARC region lies in the balancing of economic growth as well as the environment and social good through clean energy adoption, innovation, and human capital investment.

The governments of SAARC countries need to focus on regional transition to renewable energy by increasing their investment in solar, wind, hydro, and bio energy projects with the support of fiscal incentives and inter-country collaboration. The policies on industrial and energy must have better environmental standards and the encouragement of cleaner production technology in order to reduce emissions. Research can be funded, and digital infrastructure and transfer of green technology can be strengthened to help in supporting economic and environmental objectives. Sustainable tourism is supposed to be created in such a way that it produces revenues, yet at the same time it conserves the natural resources and enhances the local infrastructure. Increased education will expand environmental awareness, preventive health behavior, and the ability to be innovative. Lastly, the alignment of FDI to the standards of sustainability can make sure that foreign investments will support clean energy, technology, and healthcare industries as opposed to pollution-intensive ones to develop a balanced and inclusive growth throughout the territory of the SAARC region.

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