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# ANALYSIS OF GREEN ENERGY ON ENVIRONMENTAL SUSTAINABILITY FRAMEWORK IN PAKISTAN

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**ABSTRACT**

The use of fossil fuels and the intense industrialization of Pakistan have led to the acceleration of environmental degradation, which increases the cost of health and climate susceptibility. The shift to renewable energy source, technological achievements, and evidence-based policy are necessary to ensure economic stability, forestry protection, and preserve human health. The paper examines the correlation between green energy and sustainability in Pakistan between the years 1990 and 2022 with the help of the ARDL estimation. The explanatory variables are the consumption of renewable energy, industrial output, the importation of technology, the involvement of labor, research and development, tourism, urbanization and non-renewable energy consumption. The dependent variables will be environmental degradation, growth in economy and population health. According to the results of the Model 1 (Environmental Sustainability Model), renewable energy, foreign direct investment, tourism, and technological innovation decrease the environmental degradation, and fossil fuel use and industrial activity increase it. According to Model 2 (Economic Sustainability Model), renewable energy, industrial production, investment, labor force participation, innovation, and tourism are the economic growth enablers, but non-renewable energy also plays a role in the short run. Model 3 (Social Sustainability Model) also shows that population health is enhanced by renewable energy, tourism, labor engagement, and innovation, and it is adversely affected by fossil fuels, investment, and industrial activity. The findings highlight why Pakistan needs to increase its solar, wind, and hydropower. The study is based on the 3Ps theory (People, Planet, Profit) and emphasizes that renewable energy could be adopted to improve the social well-being, decrease ecological stress, and stimulate the economic development in the long term.

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## INTRODUCTION

In the past, economic growth has been associated with increased energy consumption and greenhouse gas emissions, which have contributed to amplified climate change and environmental degradation (Sharif et al., 2023). Although some countries have made commitments in the world under the Paris Agreement, the UN Production Gap Report (United Nations Environment Program, 2021) indicates that the current trends in fossil fuel production are higher than the climate targets. This fact underscores the pressing necessity of low-carbon transitions with the incorporation of renewable energy sources with efficiency improvements based on an innovative approach. The literature confirms that green technology and renewable energy enhance the quality of the environment and contribute to sustainable development and health outcomes (Ahmad et al., 2022; Madaleno et al., 2022; Yang et al., 2021).

Pakistan provides an example of the difficulties and prospects of such a change. Renewable capacity has increased in the country to over 9,000 MW, and the biggest facilities include the Quaid-e-Azam Solar Park and the Jhimpir Wind Corridor (Ahmad et al., 2022; Malik, 2022; Xin et al., 2022). Nevertheless, fossil fuels continue to dominate, and they maintain environmental and health-related stress. It has been discovered that renewable energy and technological innovation lessen degradation, whereas fossil fuel use exacerbates it (Ali et al., 2020; Chien et al., 2021). Tourism is another sector that has a two-sided impact: on one hand, it enriches the GDP by 6-7% and enriches cultural and ecological resources, but, on the other hand, it can cause a significant increase in environmental pressure when mismanaged (Khan, 2020).

Although the literature about energy, technology, and tourism is increasing, the majority of studies consider these drivers separately (Adebayo and Kirikkaleli, 2021; Alam et al., 2007; Munir and Riaz, 2020; Sehrawat et al., 2015). Not many evaluate their overall impact on sustainability on social, economic, and environmental levels. The current research fills that gap by empirically analyzing the role of green energy, technological innovation, and tourism in Pakistan between the years 1990 and 2022 using the ARDL approach. It is presented through the 3Ps theory: People, Planet, and Profit, contributing to the sustainability research and educating policies in accordance with the Sustainable Development Goals (SDGs 3, 7, 8, and 13). There is increasing research that explores the relationships between green technological innovation, tourism, industrial output, economic growth, environmental sustainability, and population health. The subsequent review groups these contributions and presents a summary of their area, approaches, and conclusions with a particular focus on their applicability to the sustainability framework of Pakistan in terms of the 3Ps theory (People, Planet, Profit).

**Energy and Environmental Sustainability.**

Zandi and Hasseb (2019) determined the impact of renewable energy use on environmental risks in Sub-Saharan Africa (1995-2017) through FMOLS, DOLS, and cointegration techniques, finding that renewables reduce environmental risks and globalization enhances them. This observation underscores the fact that the adoption of renewables can reduce the ecological pressure in emerging economies such as Pakistan. Qing et al. (2024) studied OECD countries (1995-2021) using PMG-ARDL estimation and determined that renewables will help decrease environmental degradation and encourage economic growth, but are positively related to oil prices. This is a twofold function of renewable energy, which directly applies to the Planet-Profit balance in Pakistan.

Magazzino et al. (2022) concentrated on Scandinavian nations (1990-2018) and found that, on the one hand, renewable energy reduces environmental risks without negatively affecting GDP, which is why it can be considered a sustainable increase. Chien et al. (2021) compared Pakistan using the QARDL techniques and concluded that renewable energy and technological advances are effective in mitigating the environmental risks, which makes it reasonable to consider green innovation as part of sustainability policies. Renewable energy also minimizes degradation in other studies in South Asia, Turkey, Malaysia, and Vietnam (Majeed and Luni, 2019; Suki et al., 2022; Tran, 2023), which also supports its universal significance. However, Chien (2022) proved that fossil fuel consumption in the Next-11 countries deteriorates the environmental quality; a timely reminder considering the fossil fuel reliance of Pakistan. On the same note, analyses carried out by both OECD and Asian economies and in developing economies indicate that non-renewable energy is always detrimental to the environment (Fakher et al., 2023; Zhang et al., 2023; Amin et al., 2023). Collectively, these results indicate the urgency of having Pakistan move at a faster rate in moving towards renewable technology so that long-term sustainability objectives can be achieved.

**Tourism and Environmental Degradation**

UNWTO (2014) estimated that international tourist arrivals would increase to 1.8 billion by 2030 with a growth rate of 3.3 a year. Tourism has become a very important component of economic development and employment.

Bekun et al. (2023) discovered that foreign tourism has a positive impact on the South African economy, and He et al. (2023), researching China in 1986-2014, established that tourism positively affects the growth of the economy but negatively affects the environment. This brings out the duality of tourism, which is sustaining Profit and jeopardizing the Planet.

Haseeb et al. (2018) used FMOLS to examine tourism and governance between 1995 and 2015. They discovered that the combined effect of tourism and good governance enhanced environmental outcomes in low-income countries. Nevertheless, tourism contributed to emissions all over the world. Likewise, Balsalobre-Lorente et al. (2020) compared OECD countries and found an inverted U-form of interdependence between tourism and environmental degradation that is aligned with the Environmental Kuznets Curve.

In the case of Pakistan, Abbas (2023) used the ARDL analysis (1990-2019) and discovered that tourism deteriorates the quality of the environment. To reduce these effects, he advised the increase in renewable energy. According to the survey of local perception, Baloch et al. (2023) indicated that tourism has positive effects on the creation of jobs and infrastructures but negatively affects the quality of the environment. Altaf et al. (2023) further compared Pakistan (1997-2022) to ARDL and affirmed the negative impact of tourism on the environment; however, tourism is positively associated with economic growth and energy consumption. Mixed results were revealed in comparative evidence published by Azam et al. (2018) in Malaysia, Thailand, and Singapore (1990-2014). Tourism minimized the environmental risks in Singapore and Thailand but maximized the risks in Malaysia, emphasising that the governance and policy environments determine the effects of tourism. In the case of Pakistan, such studies highlight the importance of sustainable tourism policies in order to strike a balance between Profit and Planet.

**Environmental Degradation and Technological Innovation.**

In a study that considered 30 countries, Chan and Lei (2018) discovered that technological innovation produced strong effects within high-emission economies, and it tended to exacerbate environmental risks. This indicates that an innovation that lacks a green orientation can be detrimental to sustainability. In the case study on China, Ahmad et al. (2023) used the ARDL model and concluded that innovation is beneficial to sustainable development, but it is also associated with a decline in the quality of the environment when not linked to the use of renewable energy. The Wavelet method was applied by Adebayo and Kirikkaleli (2021) to Japan (1990-2015). They discovered that the threats posed by globalization, productivity, and technological advancements on the environment were greater, but that renewable energy acted as a buffer. The paper has highlighted the significance of policy coordination to achieve a compromise between the growth and environmental objectives.

Chien et al. (2021) showed that in Pakistan, green energy and innovation increase the quality of the environment, whereas globalization decreases it. The same is reported by Suki et al. (2022) in Malaysia (BARDL estimation), where the research concluded that innovation and green energy reduce environmental pollution. In a study of Kazakhstan (1996-2018, DOLS), Raihan and Tuspekova (2022) found that fossil fuels and growth deteriorate emissions, whereas innovations and renewables minimise them. The results have strong implications for Pakistan, as they indicate that innovation is more than capable of protecting the Planet and maintaining Profit when combined with renewable energy.

**Industrialization, Environmental Degradation.**

In the study conducted by Alam et al. (2007), the time series was applied in studying the energy consumption and industrial growth in Pakistan. They established that as the industrial growth relies on the use of fossil fuels, it raises emissions. This brings to light the need to urgently change the industrial base of Pakistan to cleaner energy. In their study, Sehrawat et al. (2015) focused on the financial development and environmental quality in India with the use of panel econometrics. They were able to support the Environmental Kuznets Curve, where degradation of the environment increases with growth at lower income levels and then levels off. Pakistan, however, has still not attained this turning point, meaning that it remains vulnerable. Ozcan et al. (2020) examined the high-income countries, applying the panel cointegration analysis, and verified that industrial activity is the cause of ecological damage, unless combined with green energy solutions. Munir and Riaz (2020) used time-series econometrics on Pakistan and found that the use of industrial energy aggravates environmental degradation. This directly connects the industrial development of Pakistan with the sustainability issues, which supports the thesis of this study to reconcile Profit and Planet.

**Human capital, Globalization and Governance.**

Barro (2013) updated the contribution of education and human capital to help enhance growth and environmental awareness by examining the econometric variables across countries. This highlights the need for human capital in the promotion of the People aspect of sustainability. Ahmad et al. (2022) applied ARDL to examine globalization, governance, and human capital in the developing countries. They discovered that good governance and labor are the most appropriate factors that can boost the quality of the environment. To Pakistan, this is an eye-opener on how the lack of governance undermines sustainable development. Rahman and Alam (2021) studied South Asia with the help of ARDL and proved that trade openness contributes to sustainability in case of renewable energy use. This implies that Pakistan has to set trade policy in line with its environmental goals. Danish and Ulucak (2020) compared governance and globalization in the developing economies and found that effective institutions are the key to ensuring that the globalization process has a positive impact on sustainability. This shows that there is a necessity for governance reform in Pakistan so that it can create a balance between People, Planet, and Profit.

**Synthesis and Research Gap**

The papers examined all mention renewable energy, innovation, industrial activity, tourism, and human capital as key sustainability drivers. Nevertheless, most of them consider these factors separately without a detailed analysis of them as interrelated aspects of a holistic approach. In Pakistan, there are very limited studies that empirically test the combined effect of these factors on the environmental quality, the growth of the economy, and human health. This paper fills that gap using the ARDL model to help in capturing short and long-run dynamics. The study is based on the 3Ps theory, which puts sustainability within the context of People (health and human capital), Planet (environmental quality and renewable energy), and Profit (industrial development, tourism, and FDI). This cross-dimensional strategy has some novel evidence-based policymaking insights in Pakistan.

## METHODOLOGY

### Theoretical Framework

This study is based on the STIRPAT model (Stochastic Impact by Regression on Population, Affluence, and Technology). It was developed by Dietz and Rosa (1997) and has already become one of the most salient empirical instruments in environmental economics. Since it is a stochastic generalization of the IPAT identity presented by Ehrlich and Holdren (1971), the STIRPAT models the idea of environmental impact (I) as dependent upon population (P), affluence (A), and technology (T):

$$I = P \times A \times T \qquad (1)$$

The IPAT formulation, although influential, has its limitations in the assumptions that elasticities of the various units are unitary, which means that all factors have proportionate impacts on the environment. Such simplification does not allow testing the relative size of population, affluence, and technology empirically (Chertow, 2000).

STIRPAT does not assume anything and brings about loose ends via a stochastic specification:

$$I = \alpha_0 \times P\alpha_1 \times A\alpha_2 \times T\alpha_3 \times \varepsilon \qquad (2)$$

This model also enables the empirical variation of each factor in terms of its environmental impact, and thus, hypothesis testing can be done in the contribution of each factor to the others (Dietz and Rosa, 1997; York et al., 2003). The model can be generally estimated through a log-linearization:

$$\ln I = \ln \alpha_0 + \alpha_1 \ln P + \alpha_2 \ln A + \alpha_3 \ln T + u \qquad (3)$$

Where $u = \ln \varepsilon$. In this shape, the coefficients $\alpha 1$, $\alpha 2$, and $\alpha 3$ may be viewed as elasticities that capture the percentage change in environmental impact of a 1 percent change in each driver. This versatility has rendered STIRPAT a leading model in the study of carbon dioxide emission and environmental sustainability (Martínez-Zarzoso and Maruotti, 2011; Wang et al., 2016). STIRPAT has been widely used in inter-country data. The study by Shi (2003) also focused on 93 countries (1975-1996) and concluded that population pressure exerted a greater effect on CO2 emissions in developing economies. In a study including 88 developing countries, Martínez-Zarzoso and Maruotti (2011) found that urbanization and wealth were the leading factors causing emissions. The study by Rosa and Dietz (2012) verified through a global dataset that the population and economic reasons remain dominant in the growth of emissions in spite of technological changes. More directly, Karaki et al. (2023) added the digital economy to a longer STIRPAT equation using BRICS panel data between 2011 and 2021 and found that digitalization in the early phases increased emissions, but it would decrease them with economic maturity.

The STIPAT applications in Pakistan have shown the contributions of population, affluence, and energy intensity to the emissions. Ahmed and Long (2012) came up with the conclusion that the largest determinant of the CO 2 emission was population growth and the intensity of energy. Ali et al. (2017) established a significant contribution of affluence, urbanization, and use of fossil fuels to emissions in the period between 1972-2013. Shahbaz et al. (2017) further provided that both trade openness and industrialization worsened the effects of environmental degradation, but these effects could be countered by the use of renewable energy. Baloch et al. (2019) have pointed to the economic development and the energy use in South Asia, where there is poor evidence of technology-based decoupling. More recently, Ali et al. (2024) combined STIRPAT and ARDL for Pakistan and discovered that industrial activity, population, and livestock production were important drivers. Atif et al. (2024) applied STIRPAT to the growth of the financial industry (1980-2023) and found that financial growth, energy use, and GDP augmented emissions, whereas trade openness suppressed them. Anwar (2024) has studied the contribution of agricultural activities and livestock in Pakistan (1970-2020), and Anwar has found their contribution to be substantial to the CO2 emissions.

### Model Specification and Variables of Study

The study is structured around three core econometric models: the Environmental Sustainability Model, the Economic Sustainability Model, and the Social Sustainability Model. Together, these frameworks are designed to assess the effects of green energy, technological innovation, and tourism, along with relevant control variables, on environmental quality, economic growth, and population well-being in Asian countries.

***Environmental Sustainability Model***

This model is based on the effects of different explanatory variables on environmental degradation. A similar model has been used by Abbasi et al. (2020) and Nosheen et al. (2020). The model structure is as follows:

$ED = \alpha_0 + \alpha_1 GEt + \alpha_2 TIt + \alpha_3 IOt + \alpha_4 TOUt + \alpha_5 NREt + \alpha_6 HCt + \alpha_7 FDIt + \varepsilon it$ (4)

Where ED denotes environmental degradation; GE, green energy; TI, technological innovation; IO, industrial output; TOU, tourism; NRE, non-renewable energy; HC, human capital; and FDI, foreign direct investment.

***Economic Sustainability Model***

This model is based on the effects of different explanatory variables on economic growth. A similar model has been used by Nosheen et al. (2020). The model structure is as follows:

$Y = \alpha_0 + \alpha_1 GEt + \alpha_2 TIt + \alpha_3 IOt + \alpha_4 TOUt + \alpha_5 NREt + \alpha_6 HCt + \alpha_7 FDIt + \varepsilon it$ (5)

where Y = Economic Growth

***Social Sustainability Model***

The model is based on the effects of different explanatory variables on human health. Green energy ensures betterment in the lifestyle of People through better health; therefore, human health has been used as a proxy for social sustainability. A similar model has been used by Majeed & Luni (2019).

$HH = \alpha_0 + \alpha_1 GEt + \alpha_2 TIt + \alpha_3 IOt + \alpha_4 TOUt + \alpha_5 NREt + \alpha_6 FDIt + \alpha_7 EDUt + \varepsilon it$ (6)

Where HH = Human Health and EDU= Education

**Variables of the Study**

The variables used in the models are based on the studies conducted by various scholars, and the proxies used for their measurement are tabulated in Table 1.

**Econometric Methodology**

This section describes the econometric estimation methods that were used in the study, which involve unit root testing as well as the Autoregressive Distributed Lag (ARDL) method. The two approaches are elucidated and supported in the following subsections, and the strength of the findings to explore the Pakistan sustainability framework is ensured.

***Unit Root Test***

The time-series data usually have stochastic tendencies, and hence the evaluation of stationarity is a significant condition that must be adequately met before econometric analysis. We initially assess the conditions of stationarity to prevent spurious inference. A series is nonstationary when its mean, variance, and autocovariance are time-dependent; nonstationary means unit root (Enders, 2014). We perform the Augmented Dickey-Fuller (ADF) test that introduces lagged differences to overcome autocorrelation of the residues; the null hypothesis is a unit root, and rejection of the null implies I(0) (Dickey and Fuller, 1981). To be robust, we also use another nonparametric test, which is the Phillips-Perron (PP) test, which corrects serial correlation and heteroskedasticity without additional lags (Phillips and Perron, 1988; Maddala and Kim, 1998). The reason why the ARDL bounds framework is appropriate to estimate both short- and long-run relationships is that it is determined that variables are either I(0) or I(1), and not I(2) (Pesaran et al., 2001).

***ARDL Methodology***

The Autoregressive Distributed Lag (ARDL) model, which was initiated by Pesaran and Shin (1995) and polished by Pesaran et al. (2001), is suggested as a popular method to examine both long and short-run relationships. In contrast to Johansen or Engle-Granger, ARDL does not require variables that are only I(0) or only I(1), though at least not both I(2) (Nkoro and Uko, 2016). This ensures that it is very suitable in terms of macroeconomic and energy data, which are usually not integrated in the same order.

Table 1. Variables of the study.

| Dependent Variables | | | |
|---|---|---|---|
| Variables | Measurement / Proxy | Source of Variables | Data Source |
| Environmental Degradation (ED) | carbon emissions | Gillani (2023), Abbasi el al. (2020) | WDI (2023) |
| Economic Growth (Y) | GDP (const 2015 US $), GDP per capita (const 2015 US$) | Gillani (2023), Abbasi et al. (2020) | |
| Human Health (HH) | Health expense as % of GDP, | Majeed and Luni (2019), Gillani (2021) | |
| **Explanatory Variables** | | | |
| Variables | Measurement / Proxy | Source of Variables | Data Source |
| Green Energy (GE) | Renewable Energy Consumption (% of total energy consumption) | Abbasi 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), | |
| 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) | |
| Education (EDU) | School enrollment, secondary (% gross) | Abbasi et al. (2020), | |

ARDL incorporates lag values of both dependent and independent variables, representing persistence and adjustment. Long-run equilibrium is measured using the error correction term (ECT), and the bounds testing procedure is used to determine the cointegration using F-statistics. When the F-statistic is greater than the upper bound, cointegration is said to exist; when it is less than the lower bound, no cointegration exists; and between the two, inconclusive results are obtained (Pesaran et al., 2001). ARDL is particularly applicable in the case of Pakistan due to the small sample and mixed macro variables integration. It offers effective long-run forecasts and reflects the lagging impacts of green energy, technology, industry, tourism, and non-renewable energy on the sustainability indicators (Shahbaz, 2013). This paper uses ARDL in examining both equilibrium and short-term dynamics between renewable energy, technological innovation, tourism, human capital, and industrial activity, and the effects that it has on environmental sustainability, economic growth, and human health, with the 3Ps of People, Planet, and Profit.

## RESULTS AND DISCUSSIONS

In order to test multicollinearity, we resort to a correlation matrix to measure the direction and the magnitude of the pair-wise associations among the regressors. As Table 2 indicates, there is no coefficient that even comes close to unity, and therefore, multicollinearity is not an issue. The green energy consumption, technological innovation, tourism, industrial output, human capital, and non-renewable energy use are thus the right set to be explained using the ARDL framework.

### Correlation Matrix Analysis

In Table 2, the relationships between the explanatory variables and environmental degradation (ED) are evident. The strongest positive relationship (0.80) is between non-renewable energy (NRE) and the fact that the dependence on fossil fuels contributes to the decline, and the necessity of the introduction of renewable energy. There is also a positive correlation between health expenditure (HH, 0.31) and economic growth (Y, 0.24), which is indicative of the added ecological pressure of the increasing health expenditure and resource-demanding growth.

Green energy (GE) is closely related to the other two factors (positively correlated 0.19), which implies that currently it does not replace fossil fuels but supplements them. Conversely, foreign direct investment (FDI -0.52), industrial output (IO -0.39), tourism (TOU -0.34), and technological innovation (TI -0.06) are found to be associated with negative or weak mitigating effects and point towards the cleaner practices and efficiency gains.

Combined, the leadership of NRE indicates the urgency of energy changes, and the adverse correlation of FDI, IO, and TOU indicates the opportunities of the sustainable industry, eco-tourism, and innovation to enhance the quality of the environmental situation.

### Unit Root Test Results

In order to test the stationarity of the chosen variables, both the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests were used. A time-invariant variable is a place where the mean and the variance of a variable do not vary with time, which is a requirement of a valid econometric model. The results of the unit root test are reported in Table 3, and they indicate the integration order of the individual variables. The results affirm that the variables are either incorporated on the level I(0) or first difference I(1), which would validate the appropriateness of the ARDL framework in this research study.

Table 2. Correlation Matrix.

| Correlation | ED | Y | HH | GE | FDI | HC | EDU | IO | TI | TOU | NRE |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ED | 1.00 | | | | | | | | | | |
| Y | 0.24 | 1.00 | | | | | | | | | |
| HH | 0.31 | 0.45 | 1.00 | | | | | | | | |
| GE | 0.19 | 0.20 | 0.13 | 1.00 | | | | | | | |
| FDI | -0.52 | -0.41 | -0.41 | -0.11 | 1.00 | | | | | | |
| HC | -0.23 | 0.57 | 0.71 | 0.26 | -0.13 | 1.00 | | | | | |
| EDU | 0.21 | 0.32 | 0.43 | 0.20 | -0.28 | 0.48 | 1.00 | | | | |
| IO | -0.39 | 0.68 | -0.09 | 0.06 | 0.12 | 0.48 | 0.11 | 1.00 | | | |
| TI | -0.06 | -0.85 | -0.28 | -0.20 | 0.25 | -0.59 | -0.31 | -0.77 | 1.00 | | |
| TOU | -0.34 | 0.75 | 0.29 | 0.17 | 0.03 | 0.79 | 0.29 | 0.86 | -0.73 | 1.00 | |
| NRE | 0.80 | 0.23 | 0.53 | 0.27 | -0.74 | 0.09 | 0.35 | -0.39 | -0.10 | -0.21 | 1.00 |

Table 3. Unit root test.

| Variable | Integration Order | Augmented Dickey Fuller Unit Root Test | | | | |
|---|---|---|---|---|---|---|
| | | Critical Value | | | T Statistics | Prob Value |
| | | 1 % | 5 % | 10 % | | |
| ED | I(0) | -3.64 | -2.95 | -2.61 | -2.76*** | 0.07 |
| | I(1) | -3.75 | -2.99 | -2.63 | -4.64* | 0.001 |
| Y | I(0) | -4.27 | -3.55 | -3.55 | -4.59* | 0.0045 |
| | I(1) | -------- | ------ | ----- | ------- | -------- |
| HH | I(0) | -3.65 | -2.95 | -2.61 | -2.24 | 0.19 |
| | I(1) | -3.66 | -2.96 | -2.61 | -4.64* | 0.0008 |
| GE | I(0) | -3.65 | -2.95 | -2.61 | -1.75 | 0.39 |
| | I(1) | -3.66 | -2.96 | -2.61 | -4.77* | 0.0006 |
| IO | I(0) | -3.65 | -2.95 | -2.61 | -2.13 | 0.23 |
| | I(1) | -3.66 | -2.96 | -2.61 | -5.59* | 0.0001 |
| HC | I(0) | -3.65 | -2.95 | -2.61 | -3.74* | 0.0079 |
| | I(1) | ----------- | ----------- | ----------- | ----------- | ----------- |
| TOU | I(0) | -3.65 | -2.95 | -2.61 | -1.55 | 0.49 |
| | I(1) | -3.66 | -2.96 | -2.61 | -4.68* | 0.007 |
| FDI | I(0) | -3.67 | -2.96 | -2.62 | -1.65 | 0.44 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | I(1) | -3.65 | -2.95 | -2.61 | -3.01** | 0.04 |
| NRE | I(0) | -3.65 | -2.95 | -2.61 | 0.48 | 0.98 |
| | I(1) | -2.66 | -1.95 | -1.60 | -4.48* | 0.001 |
| TI | I(0) | -3.65 | -2.95 | -2.61 | -1.56 | 0.48 |
| | I(1) | -3.66 | -2.96 | -2.61 | -5.10* | 0.0002 |
| EDU | I(0) | -3.72 | -2.98 | -2.63 | -3.69** | 0.01 |
| | I(1) | ----------- | ----------- | ----------- | ----------- | ----------- |
| Variable | Integration Order | Phillips - Perron Test Statistic | | | | |
| | | Critical Value | | | T Statistics | Prob Value |
| | | 1 % | 5 % | 10 % | | |
| ED | I(0) | -3.64 | -2.95 | -2.61 | -2.71*** | 0.08 |
| | I(1) | -3.66 | -2.96 | -2.61 | -4.78* | 0.0006 |
| Y | I(0) | -4.26 | -3.55 | -3.20 | -4.37* | 0.007 |
| | I(1) | ----------- | ----------- | ----------- | ----------- | ----------- |
| HH | I(0) | -3.65 | -2.95 | -2.16 | -2.47 | 0.13 |
| | I(1) | -3.66 | -2.96 | -2.61 | -4.67* | 0.0007 |
| GE | I(0) | -3.65 | -2.95 | -2.61 | -2.21 | 0.20 |
| | I(1) | -3.66 | -2.96 | -2.61 | -4.99* | 0.0003 |
| FDI | I(0) | -3.64 | -2.95 | -2.61 | -1.71 | 0.41 |
| | I(1) | -2.63 | -1.95 | -1.61 | -2.53** | 0.01 |
| IO | I(0) | -3.65 | -2.95 | -2.61 | -2.15 | 0.22 |
| | I(1) | -3.66 | -2.96 | -2.61 | -5.59* | 0.0001 |
| NRE | I(0) | -3.65 | -2.95 | -2.61 | 0.37 | 0.97 |
| | I(1) | -3.66 | -2.96 | -2.61 | -4.49* | 0.001 |
| HC | I(0) | -3.65 | -2.95 | -2.61 | -3.72* | 0.0084 |
| | I(1) | ----------- | ----------- | ----------- | ----------- | ----------- |
| TOU | I(0) | -3.65 | -2.95 | -2.61 | -1.59 | 0.47 |
| | I(1) | -3.66 | -2.96 | -2.61 | -4.83* | 0.0005 |
| TI | I(0) | -3.65 | -2.95 | -2.61 | -1.88 | 0.33 |
| | I(1) | -3.66 | -2.96 | -2.61 | -5.13* | 0.0002 |
| EDU | I(0) | -3.64 | -2.95 | -2.61 | -2.68*** | 0.08 |
| | I(1) | -3.65 | -2.95 | -2.61 | -5.78* | 0.0001 |

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

The unit root tests reveal mixed integration orders, which prove the appropriateness of ARDL. Education, economic growth, environmental degradation, and human capital remain at level [I(0)], and industrial output, tourism, technological innovation, health expenditures, green energy, and non-renewable energy remain stationary once [I(1)] has already been differentiated first [I(2)]. Such a combination demonstrates the benefit of ARDL compared to the conventional cointegration techniques, where all the variables must have the same integration order.

**ARDL Bounds Test for Cointegration**

All three models have stable long-run relationships as indicated by the ARDL bounds test results in Table 4. The F-statistic (4.17) of model 1 is greater than the 1% critical bounds, and this proves that the environment framework is co-integrated. The best evidence is found in Model 2, where the F-statistic of 43.82 is far above the upper bound. Cointegration is also supported by Model 3, where the F-statistic equals 4.93, which is greater than the 1% level. Comprehensively, these findings form long-run equilibrium relationships among environmental, economic, and social modelling, which opens the path to the ARDL regression to determine the short-run and long-run impacts on the sustainability outcomes.

***Model 1: Environmental Sustainability Results***

Model 1 estimates the ARDL both in the short and the long run, which indicates that environmental degradation (ED) in Pakistan has short-and long-term drivers as shown in Table 5.

Table 4. ARDL bound test.

| Model 1 | | | Model 2 | | Model 3 | |
|---|---|---|---|---|---|---|
| Null Hypothesis: No long-run relationships exist | | | | | | |
| Test Statistic | Value | K | Value | | Value | |
| F-statistic | 7.180544 | 7 | 43.82049 | | 4.936917 | |
| Critical Value Bounds | | | | | | |
| Significance | I0 Bound | I1 Bound | I0 Bound | I1 Bound | I0 Bound | I1 Bound |
| 10% | 2.03 | 3.13 | 2.16 | 3.24 | 1.88 | 2.99 |
| 5% | 2.32 | 3.5 | 2.43 | 3.56 | 2.14 | 3.3 |
| 2.5% | 2.6 | 3.84 | 2.67 | 3.87 | 2.37 | 3.6 |
| 1% | 2.96 | 4.26 | 2.97 | 4.24 | 2.65 | 3.97 |

Table 5. 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) | -0.021025 | 0.002366 | -8.887901 | 0.0000 |
| D(IO) | 0.010799 | 0.003408 | 3.168331 | 0.0064 |
| D(HC) | -0.002852 | 0.001255 | -2.272739 | 0.0382 |
| D(FDI) | -0.000087 | 0.002124 | -0.040815 | 0.9678 |
| D(TOU) | -0.032516 | 0.016046 | -2.026433 | 0.0609 |
| D(NRE) | 0.004529 | 0.002494 | 1.816162 | 0.0870 |
| D(TI) | -0.365159 | 0.156292 | -2.336383 | 0.0263 |
| CointEq(-1) | -0.558960 | 0.187324 | -2.983918 | 0.0071 |
| Long Run Coefficients | | | | |
| Variable | Coefficient | Std. Error | t-Statistic | Prob. |
| GE | -0.018265 | 0.002187 | -8.349885 | 0.0000 |
| IO | 0.012859 | 0.002883 | 4.460833 | 0.0005 |
| HC | -0.004818 | 0.001295 | -3.719368 | 0.0021 |
| FDI | -0.067687 | 0.013447 | -5.033630 | 0.0001 |
| TOU | -0.028246 | 0.014067 | -2.008052 | 0.0630 |
| NRE | 0.008157 | 0.002623 | 3.110247 | 0.0064 |
| TI | -0.074520 | 0.032762 | -2.274601 | 0.0380 |
| C | 3.387910 | 0.699638 | 4.842374 | 0.0002 |

Renewable energy also has a major impact on ED in the short run (-0.021, $p < 0.01$), which highlights the immediate advantages of clean energy use. The reverse is true in the case of industrial production (0.011, $p < 0.01$), which is the ecological costs of growth without cleaner technologies. Human capital is a contributor to reducing ED (-0.003, $p < 0.05$), and tourism has a rather positive but slightly negative influence (-0.033, $p \approx 0.06$). The consumption of non-renewable energy sources is only a short-run source of degradation (0.005, $p \approx 0.09$). The greatest mitigating effect (-0.365, $p < 0.05$) is seen in technological innovation, which shows its contribution to cleaner production. The negative error correct term is highly significant (-0.559, $p < 0.01$), which means that the equilibrium is restored at the rate of 56 percent per year.

Over the long term, these dynamics are confirmed, with renewable energy (-0.018, $p < 0.01$), human capital (-0.005, $p < 0.01$), FDI (-0.068, $p < 0.01$), tourism (-0.028, $p \approx 0.06$), and technological innovation (-0.075, $p < 0.05$) mitigating ED, and industrial output (0.013, $p < 0.01$) and fossil fuels (0.008, $p < 0.01$) exacerbate it.

All these results prove that the sustainability of the Pakistani environment depends on the infrastructure development of renewable resources, the human capital development, promotion of innovations, and the orientation of the FDI and tourist directions to green technology. Meanwhile, the unregulated industry and fossil fuel dependencies are still present. This balance encompasses the Planet aspect of the 3Ps, underlining the urgency of energy reforms and stricter industrial policies.

Table 6. 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) | 0.003722 | 0.000802 | 4.638572 | 0.0035 |
| D(FDI) | 0.005870 | 0.000916 | 6.406834 | 0.0007 |
| D(IO) | 0.009346 | 0.002249 | 4.155444 | 0.0060 |
| D(HC) | 0.921100 | 0.544455 | 1.691784 | 0.1128 |
| D(TOU) | 0.012256 | 0.009395 | 1.304569 | 0.2398 |
| D(NRE) | 0.002004 | 0.000533 | 3.761492 | 0.0094 |
| D(TI) | 0.167329 | 0.012952 | 12.919067 | 0.0000 |
| CointEq(-1) | -0.206372 | 0.047227 | -4.369821 | 0.0006 |
| Long Run Coefficients | | | | |
| Variable | Coefficient | Std. Error | t-Statistic | Prob. |
| GE | 0.010715 | 0.000448 | 23.926450 | 0.0000 |
| FDI | 0.076432 | 0.027182 | 2.811878 | 0.0097 |
| IO | 0.056062 | 0.116652 | 0.480592 | 0.6382 |

| | | | | |
|---|---|---|---|---|
| HC | 0.001861 | 0.000251 | 7.427821 | 0.0003 |
| TOU | 0.010464 | 0.001865 | 5.610511 | 0.0014 |
| NRE | 0.001704 | 0.000458 | 3.720621 | 0.0098 |
| TI | 0.086326 | 0.005088 | 16.965701 | 0.0000 |

***Model 2: Economic Sustainability Results***

The ARDL estimates of Model 1 in Table 6 indicate both the short and long-run predictors of environmental degradation (ED) in Pakistan.

Renewable energy has a considerable ED (-0.021, $p < 0.01$) impact in the short run, which highlights the immediate advantages of the use of clean energy. The same does not apply to industrial output (0.011, $p < 0.01$), which represents the ecological costs of growth that does not assume cleaner technologies. Human capital has a negative impact on ED (-0.003, $p < 0.05$) and tourism has a positive effect, albeit insignificantly (-0.033, $p \approx 0.06$). The use of non-renewable energy is still a short-term cause of degradation (0.005, $p \approx 0.09$). The most significant mitigating effect is that of technological innovation (-0.365, $p < 0.05$), which puts it in the spotlight of cleaner production. The negative error correction value is also substantial (-0.559, $p < 0.01$), which means that the equilibrium will be restored with the adjustment rate of 56 per cent per year.

These dynamics are confirmed in the long run: renewable energy (-0.018, $p < 0.01$), human capital (-0.005, $p < 0.01$), FDI (-0.068, $p < 0.01$), tourism (-0.028, $p \approx 0.06$), and technological innovation (-0.075, $p < 0.05$) all lower ED, whereas industrial output (0.013, $p < 0.01$) and fossil fuels (0.008, $p < 0.01$).

Collectively, these results indicate that environmental sustainability in Pakistan is pegged on the need to grow renewables, enhance human capital, promote innovation, and steer FDI and tourism to green activities. Meanwhile, uncontrolled industrialization and the use of fossil fuels are still looming threats. This equilibrium represents the Planet aspect of the 3Ps, with the priority given to energy reforms and tighter industrial policies.

***Model 3: Social Sustainability Results***

Model 3 in Table 7 considers social sustainability on the basis of health expenditures (HE) as a measure of population welfare.

Short-run Renewable energy is also less polluted, and less polluted air is reflected in HE (-0.031, $p < 0.05$). Sustainable tourism also reduces HE (-0.242, $p < 0.05$), which indicates that sustainable tourism enhances health due to income and community effects. The mitigating impact of technological innovation is high (-0.365, $p < 0.05$, below 0.05), and the exacerbating effect of fossil fuels is modest (0.007, p below 0.05). Industrial production is positive yet insignificant (0.030, p 0.09). The negative but insignificant relationships are between education and FDI. The error correction value (-0.512, $p < 0.01$) shows that it will be adjusted to equilibrium at an approximate rate of 51 percent per year.

Green energy is still negative ( -0.081, p = -0.06) in the long run, which indicates long-term health benefits of renewables. The social sustainability is enhanced by tourism (-0.473, $p < 0.05$) and FDI (-0.100, $p < 0.05$), but education only has a marginal impact (-0.028, $p \approx 0.08$). The fossil fuels are still increasing HE (0.020, $p < 0.05$), and the industrial output is still slightly detrimental (0.060, $p \approx 0.09$). The positive aspect of innovation in technology becomes irrelevant but significant, meaning that it can only be realized in the presence of stronger institutions.

Renewables, tourism, education, and the FDI are positive in enhancing social sustainability in Pakistan, whereas dependence on fossil fuels and unregulated industry deteriorates health outcomes. These findings go in line with the People aspect of the 3ps, and support the inquiry of clean energy shifts, eco-tourism, and health-conscious policies to achieve SDG 3, SDG 4, and SDG 7.

Table 7. 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) | -0.031309 | 0.013446 | -2.328462 | 0.0325 |
| D(IO) | 0.029982 | 0.016850 | 1.779295 | 0.0879 |
| D(EDU) | -0.237837 | 0.788714 | -0.301550 | 0.7686 |
| D(TOU) | -0.242288 | 0.100106 | -2.420323 | 0.0270 |
| D(FDI) | -0.022796 | 0.013459 | -1.693790 | 0.1184 |
| D(NRE) | 0.006957 | 0.003079 | 2.259338 | 0.0332 |
| D(TI) | -0.872939 | 0.338118 | -2.581755 | 0.0174 |
| CointEq(-1) | -0.511773 | 0.113308 | -4.516663 | 0.0003 |
| Long Run Coefficients | | | | |
| Variable | Coefficient | Std. Error | t-Statistic | Prob. |
| GE | -0.081499 | 0.040308 | -2.021879 | 0.0592 |
| IO | 0.059824 | 0.033706 | 1.774886 | 0.0938 |
| EDU | -0.028337 | 0.014972 | -1.892588 | 0.0756 |
| TOU | -0.473429 | 0.207492 | -2.281676 | 0.0357 |
| FDI | -0.100108 | 0.044335 | -2.257992 | 0.0453 |
| NRE | 0.020274 | 0.009153 | 2.214948 | 0.0365 |
| TI | 0.354068 | 0.371103 | 0.954096 | 0.3534 |
| C | 22.003971 | 9.351780 | 2.352918 | 0.0309 |

## CONCLUSIONS AND RECOMMENDATIONS

Renewable energy is a decisive factor that enhances the quality of the environment as well as resilience of the economy. The rapid transition to clean energy can be crucial to decreasing emissions and improving the population well-being. Tourism is a potential source of sustainable growth when it is done responsibly and in this regard, tourism is known to boost growth, conservation of the environment, and social welfare at the same time. This is achieved through technological innovation, which is enhanced by effective systems of education and institutions, reducing ecological risks and enhancing productivity and competitiveness. Despite the fact that industrial growth spurs the short run economic growth, the unrestricted emission and waste products of industries continue to put a strain on the health and environmental systems, which ratifies the necessity of more stringent regulation. Besides, the pollution-halo effect of FDI is an indicator that environmentally-sensitive investment can facilitate the realization of sustainable industrial transformation in the context of Pakistan when FDI is channeled to the clean technologies and efficient production systems.

Pakistan needs to invest heavily in renewable energy; solar, wind as well as hydropower, and promote energy conservation in households, transport as well as industries. This plan would decrease the reliance on fossil fuels, decrease emissions, and create green jobs that comply with SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action). Eco-friendly practices, conservation of heritage and community-based programs should be encouraged to enhance the foreign exchange revenue, employment opportunities, and health, which aligns with SDG 8 (Decent Work and Economic Growth). Increasing the investment in R&D and encouraging government-academic-industrial collaboration will expedite the process of technological adaptation and diffusion, and human capital development through training in green technologies will help to promote SDG 4 (Quality Education). The strict environmental standards, the waste management policy, and the safety rules at the workplace should be imposed by the industrial policy to reduce the ecological pressure and preserve the competitiveness. Lastly, Pakistan must create specific incentives in order to encourage foreign investment in renewable energy, sustainable tourism and cleaner production to direct foreign capital into the areas that support and not weaken environmental sustainability.

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