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Investigation the impact of Information & Communication Technology, Foreign Direct Investment and Renewable Energy on Ecological Footprint? Evidence from South Asian Countries

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Abstract
Today, environmental deterioration has become a serious problem throughout South Asia. The macroeconomic factors that influence the environmental quality across various regions must therefore be modelled. Under such circumstances, this study explores that how ecological footprint effected by information & communication technology, foreign direct investment, renewable energy for South Asian countries by utilizing panel data from 1990 to 2018. We use Granger Causality method and autoregressive distributed lag ARDL to check the cointegration, the long and short-term association and cointegration. The aggregate empirical results show a long-term, strong negative association among information & communication technologies, foreign direct investment and ecological footprint. On the other side, renewable energy positively and sustainably correlated with ecological footprint which reduce environmental degradation. Both Environmental Kuznets curves (EKC) and pollution haven hypothesis support our findings. Additionally, the findings show that developing information & communication technologies, making the switch to renewable energy sources and restricting foreign direct investment inflows are crucial for halting environmental degradation in the concerned South Asian nations. Numerous policies related to improve environmental welfare are advised in light of these findings.
Keywords: ICT index, foreign direct investment, renewable energy, EKC, PHH, South Asian countries

1. Introduction

The main obstacle to global sustainable development is environmental degradation which is caused by rising greenhouse gas (GHG) emissions. Since, carbon dioxide emissions make up the biggest portion of greenhouse gases and have the most readily available statistics, that have been employed as an environmental indicator. CO_2 emission, however, are not constant. For instance, CO_2 emissions, according to, can be poor indication, similarly for energy resources such as, forests and mining, oil and soil. So, in order to control environmental quality for sustainable development, we needed a most appropriate factor. According to, environmental deterioration is usually measured using ecological footprint, which is regarded as ecological sustainability in this context (Amin et al., 2024). The ecological footprint gauges how much consumption is a result of human activities. Therefore, in order to fulfill the sustainable development goals of United Nations, we employ EFP as an indicator of environmental deterioration measure in our study. This research explores the effect of information & communication technology, FDI, REU on ecological footprint. We also looked at some control variables which also harm the environment like, economic growth and trade openness. To accomplish the stated goal, this study takes the South Asian nations as a case study. In some instances, 3 of the biggest South Asian nations India, Bangladesh and Pakistan are among the world's top five too much polluted in terms of the air quality. In addition, South Asia is home to top 27 the most contamination cities in the world the other hand, when it comes to air contamination, from 2000 to 2019, the amount of greenhouse gas emissions has expanded about twofold in SA countries. Ecological footprint is currently a solid sign of environmental contamination (Parveen et al., 2024).

The use of ICTi for GDP is tied to environmental sustainability. In the modern world, ICTi is crucial to enhancing human welfare and fostering economic development. According to various researchers there is an inverse relationship among ICTi and ecological footprint and it lessen environmental degradation like, Hence, to analyze the effect of ICTi on ecological footprint is key because of increasing information & communication technology development in South Asian economies (Sadia Bint Raza et al., 2024) By using the internet, mobile devices, satellites to monitor and mitigate climate, information & communication technology also supports the environmental goals of the SGDs. So that, there is a need to address the ICTi combating environmental problems. It is admirable how it effects a number of social and economic sector, including business, the environment, education, trade, services and FDI as well as developed financially. In contrast, many researchers found ICTi rise level of EFP which caused an increase in environmental degradation such as (Zubair et al., 2024).

As a component of information & communication technology, foreign direct investment is crucial to the diffusion of technology. High technology, job opportunities and capital are crucial for a country's economic success. However, in the past, researcher focused on FDI to determine its impact on EFP. As per (CGIT) China Global Investment Tracker, FDI in South Asia is heavily focused on sustainable power. Investment in the energy sector makes up a large portion of foreign direct investment in South Asian nations (Song et al., 2024). The benefits and drawbacks of foreign direct investment must therefore still warrant careful consideration. The relationship among REU, quality of life, climate change, sustainable development and GDP has been covered in existing literature and. Additionally, only a couple of studies with a restricted scope are described, like (Rabbia Syed, Sehrish Arshad, Saif Ur Rahman, 2024).

Energy use is a necessary yet irreplaceable component of manufacturing and production. As a result, the majority of countries economic development depends heavily on their use of energy. Energy is likewise in accordance with SGD 7 of UN's sustainable development plan for 2023. Moreover, to fulfill the need of energy, different countries are used wind power, solar, energy, coal energy, and natural gas etc. The EFP is impacted by the ongoing use of these conventional energies and. By larger part of South Asian countries broad utilization of fossil fuels has been primary factor in the region's environmental degradation (R. Saeed et al., 2024). The major South Asian nations now produce only a small level of their power from renewable sources. This aspect can largely due to the technological, energy and infrastructure challenges that these nations face, as a result, these limitations have greatly restricted the capacity of fossil fuel industry (Shen et al., 2024).

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In comparison to Bangladesh, Pakistan, Nepal and Sri Lanka, India has the highest level of economic development. India's economy currently consumes the most energy in the region, according to, when the economy grow, need for energy rises as well. Examining the environmental standard of these developing nations is the aim of this study in order to assist policymakers in creating appropriate ICTi and FDI that protect the environment, promote GDP and invigorate the technology use (Huang et al., 2024).

Furthermore, the remaining research is divided into five parts. Sec. 1 the "Literature Review" discuss the review of literature. Sec. 2 "Theoretical Base" this section presents the theoretical foundation of the variables. Sec. 3 "Data and Methodology" where details about the data and model specifications are presented together with the data and approach. Sec. 4 "Econometric Methodology" this section presents the econometric equations of the technique used in this study for empirical findings. Sec. 5 "Empirical Results and Discussion" the empirical results of the many tests were employed in the study are presented. "Conclusion and Policy Recommendations" in section 6 gives the study findings and some policy implications.

2. Review of Literature

There have been numerous studies conducted, on the impact of ICTi, FDI and REU on environmental degradation. We have added a number of explanatory macroeconomic variables to the body of literature that are crucial for encourage FID and economic growth as well as for developing infrastructure related to ICTi as well as REU. In this section of study, we look at how the ecological footprint is affected by ICTi, foreign direct investment and renewable energy use. The review of past studies is divided into different segments to explain how the numerous variables included in this research connect with one another (Audi et al., 2021; Arshad et al., 2024; Saeed et al., 2024; Maqsood et al., 2023).

In the past few decades, ICTi industries are one of the very competitive industries has been grown rapidly. The flow of data used by government, business and consumers preferences has increasing extensionally. Information and communication technology play duel important role to control environmental degradation. First, through the use of REU sources and energy efficiency, ICTi can stop environmental damage. ICTi have protentional to lower emissions across the economy, which is more significant (Minhas et al., 2024; Abro et al., 2024) Environmental researchers have reported mixed results regarding ICTi and ecological footprint. To support high levels of EFP, ICTi require more energy to function properly and smoothly, according to some researchers. For example, , from 1995 to 2019, the study examines Pakistan's Information & Communication Technology and EFP in the short, long-term. The QARDL method used for time series and panel data estimation. Their results show significant impact of ICTi on EFP. According to empirical research by, countries of (E7), (G7) from 1995 to 2018, there is a correlation among information & communication technologies and ecological footprint. For analysis this study performs cross sectional dependency used second generation method. The empirical findings show negative and significant impact on E-7 countries, moreover, G-7 countries significantly upgrade the quality of environment in both panel countries (Shahid, 2024; Irfan et al., 2023). Using the Johnsen Cointegrations approach and (VECM) vector error correction method, analyses that how environmental degradation effected by ICTi on the kingdom of Saudi Arabia. This study demonstrated both long and short-term relationship between information & communication technology and ecological footprint. Some researchers like, demonstrate that how information & communication technology reduce environmental degradation and encourage energy efficiency in the industrial process. Information & communication technology, on the other hand, may be a vital instrument for boosting environmental sustainability, according to recent researchers (Audi et al., 2022; Shahid, 2023; Shahid et al., 2023).

For instance (Dawood et al., 2023), found that ICTi has an opposite relationship with EFP, in the kingdom of Saudi Arabia from 1980 to 2019. Unit root method like, augmented dickey-fuller, and phillips perron, were examined in this research, as well as also applied ARDL approach. In this regard, used AGM technique to investigate that internet use in these nations has no impact on ecological footprint. The connection between information & communication technology and environmental pollution from OECD economies was also investigated by the. The authors of the report claim that ICTi does not degrade environmental quality. For the years of 1995 to 2016 (T. A. Shahid, 2024c) employed the second generation panel data approach to examine the effects of non-renewable energy use, large-scale emerging financialization and environmental deterioration. The results demonstrate that technical innovation doesn't have a sustainable effect on ecological footprint, but it is effective at reducing carbon emissions. According to, the impact of trade in ICTi, alternative energy sources and natural gas, fired electricity on GDP and CO_2 in Africa is in the list of top 3 natural gas produced economies from 1990 to 2020. (T. A. Shahid, 2024b) This study used random, pooled and fixed effect models. The empirical findings indicate that ICTi strongly and positively corelated with economic progress. Based on the empirical data, the policymakers should use wind and solar, coal and natural gas, etc. as a transitional REU source and recognize the benefits to the sustainable improvement in commerce such as ICTi can make to economic development and healthy environment (Ullah et al., 2023; Qureshi et al., 2022).

As one of the primary means of transferring technology and enhancing the industrial structures of recipient nations, foreign direct investment has also received extensive literary attention for its role in contributing to environmental contamination. Examining the connection among FDI and environmental degradation, has become more crucial in the modern era because of worries about climate change and global warming. (Zulfiqar et al., 2022), employed OLS and robust regression on a sample of 53 countries from 1980 to 1995 to support his claim that FDI in manufacturing has a favorable influence on environmental impacts in emerging and underdeveloped nations, but his little impact in wealthy ones. There are numerous studies, including those by (Javaid et al., 2023), and explore that there is a strong link among FDI and EFP. To analyze the relationship among FDI and ecological footprint form 1990 to 2016 (Awan et al., 2023), used panel vector autoregression. FDI and ecological footprint have a biodirectional link, according to empirical research. Some studies found that FDI helps to lower environmental degradation, also discover a bad relationship between FDI and ecological footprint., use the FMOLS, DOLS, CRR, and spectral causality methodologies to examine how FDI affect EFP empirical data. For the period of 1990 to 2017, ecological footprint is positively affected by FDI in China. In order to examine how FDI affected Nigeria's ecological footprint form 1970 to 2017(Ur Rahman & Bakar, 2019), used Granger Causality, the Zivot-Andrews unit root test, conventional unit root testing and ARDL methodology. Findings of this study shows a unidirectional relationship among FDI an EFP. According to(Chaudhary et al., 2023), this empirical research examine the association among FDI, energy dependence and CO_2 in the GCC, economies form (1996-2019). The results demonstrate that FDI cut CO_2 emissions and the technique used to investigate these results is called

FMOLS. In their study of the EKC and the PHH from 1990 to 2020, of sixteen European nations. Both augmented mean group test and Dumitrescu and Hurlin panel causality are used to analyze the relationship between FDI and EFP. The association between FDI and EFP is examined applying both Dumitrescu and Hurlin panel causality and augmented mean group test. The empirical findings revealed unidirectional causality relationship between lags (ARDL) for analysis for the period of 1970 to 2021 in China. According to empirical findings FDI negatively affect the environmental degradation.

Numerous studies on EFP and REU have carried out. Ecological studies have given much thought to the relationship among ecological footprint and the use of energy. As an industrialized economy, its demand for energy is likely rise, according to the structural change theoretical approach. This is due to the fact that, given the importance of energy as an industrial input, the extraction and combustion of fossil fuels to meet energy demands, particularly in South Asian nations that rely heavily on them, can be predicated to result in an increase in GHGs emissions including CO_2 (A. U. Shahid et al., 2022). Ecosystem destruction, often known as environmental degradation, the most urgent concerns the global world facing now a day. among others, it has been proven that GHG emission is the main reason of environmental deterioration, which is a major cause of overuse and waste of non-renewable energy, used Augmented mean group estimator, penal cointegration and penal regression methods, for the period of 1990 to 2014, used penal data sample of 28 OECD countries. This study concluded that renewable energy helps OECD nations combat the issue of environmental degradation. According to the experimental results there is a positively significant, association among REU and environmental degradation in the long-term, on the other hand, insignificant in short-run, by. Granger causality and PMG / ARDL methods was applied in the study of, in MINT economies, from 1971-2017, with the bootstrapped BARDL methodology, Malaysian researchers studied the connection between REU, EGC and ecological sustainability. Results showed that renewable energy use increases the reduction in the level of pollution in the environment. This co-integration test was applied to a data set spanning 107 low and high-income countries from 1990 to 2019 in, study. The empirical findings show that in some places, REU and EFP are positively correlated in low income economies. However, the results of REU and CO_2 are opposite in low-income areas (Zahra et al., 2023).

Originate that the usage of REU plays a significant role in reducing the EFP of South Asian regions, both directly and indirectly, by applying cross-sectional, (CS) dependence, heterogeneity slope, and structural gaps issues in the data. Additionally, the elasticity estimates support the EKC and PHP pollution haven hypothesis as being true. Similarly, literary research reveals that the utilization of renewable resources in these nations had led to a decreasing trend in EFP, according to some studies like as well as., this empirical analysis examines how energy factors across the developed G7 and rising E7 countries have affected ecological footprints from 1990 to 2000. In addition, the study applied robust panel estimate method was applied and empirical findings indicate that the utilization of REU and EFP are negatively correlated in both economies. The basic objective of this study (Rahman, 2019) was to look into how the world's top countries throughout the period of 1994 to 2018 have changed energy consumption. Furthermore, this study uses moment quantile regression to examine the direct and indirect impact of environmental taxes, REU on EFP. As per findings, REU directly and considerably reduces ecological footprint, which is examined by using robustness of the MMQR results, DOLS, FMOLS and GMM approach (Shahzadi, Sheikh, et al., 2023).

3. Theoretical Framework

The impact of environmental degradation on information & communication technology, foreign direct investment and renewable energy, control variables like economic growth and trade openness has been subject of several research theories. Here, we discuss the EKC and PHH theories.

a. EKC (Environmental Kuznets Curve Hypothesis)

This theory describes the relationship among EKC and economic growth. As reported by the theory, contamination rises as per capita income rises and eventually, as economic growth rises, by creating a U-shape curve. In essence, it demonstrates how environmental quality declines as a result of GDP before improving. Three channels are identified while analyzing the environmental Kuznets curve, which are scale effect, composition effect and technique effect by. The scale effect occurs when economic growth picks up speed, in according to this study. The demand for natural resources rises as a result, but at the same time, the manufacturing process replaces the consumption of these resources. Due to the massive production of environmentally hazardous industrial waste, which accelerates both environmental deterioration and economic expansion, this is a threat to the environment. The composition effect is the gradual transformation of the industrial structure that occurs as income rises, transforming the structure of the economy (Zhao et al., 2023). In this stage, companies start to adopt cleaner technology and the secondary sector starts to mature, the results from economic expansion favorably impacts how the environment handled. Environmental consciousness increases as a result of this period, which fuels technological development and trickle-down effect on the economy. As the economy invests in research & development activities and transitions to a more knowledge-intensive economy, the tertiary or services sector grows at this point. By forcing replacement of pollution-producing equipment, it improves the quality of the environment and stimulates economic growth.

b. Pollution Haven and Halo Hypothesis (PHH)

PHH (Pollution haven theory, and Pollution halo hypothesis), are important theories which best explains the association between foreign direct investment and contamination about environment. The pollution haven hypothesis states the countries with lax environmental rules promote the growth of sectors that produce large amounts of pollution, which in turn attract more foreign direct investment and rise global pollution level (Tabassum et al., 2023) In developed countries, the adoption of clean or green technologies is expensive and environmental rules are strict. As a result headquarters to developing countries (Li et al., 2022), in order to get amount these restrictions and costs. Competitions and nations have a good effect on sustainable advancement through the employment turnover mechanism and the demonstration effect, according to Pollution Halo Hypothesis of. In order to compete with multinational corporations, notes that domestic businesses also work to improve the quality of their output. On the pollution halo hypothesis ecological acts of foreign organizations are contrasted with local counterparts rather than industry position. Since foreign direct investment reduce air pollution, it is hypothesized that it will have positive ecological aftereffects. Multinational businesses (MNCs) may be able to reverse ecological deterioration in a developing host country by implementing new green technologies in addition to revived conservation-related reputational strategies (Rahman et al., 2022).

c. Methodology and Model Specification

In this study we use panel data for South Asian nations from 1990 to 2018 from the Global Ecological Footprint Network (2018), and World Development Indicators,(Hakim AliAnalyzing the Link between Distributed Leadership and Teachers' Self-Efficacy Beliefs at Secondary School Level et al., 2021), in order to conduct an empirical analysis. Ecological footprint is dependent variable of this study is an indicator of environment global hectare per capita and independent variables are Information & communication technology index, renewable energy proxy (per capita of energy use), foreign direct investment (FDI inflows % of GDP). Our control variables include economic growth (GDP) and imports and exports of goods and services as proxy of trade openness. Environmental Kuznets Curve, and pollution haven hypothesis are followed by our study. At initially, economic expansion was placed over environmental protection, but as economic development advanced, people began to cherish the environment and demand legislation that would protect it. Moreover, contamination haven / hallo theory suggests positive / adverse impact of FDI on the environmental degradation. Measurement of variables and its source of data is described in Table 1.

Table 1: Measurement of variables and data source

Variable	Symbols	Unit of Measurement	Source
Ecological Footprint	EFP	per capita global hectare	WDI
Renewable Energy	REU	per capita of energy use	WDI
Foreign Direct Investment	FDI	FDI inflows % of GDP	WDI
Information and Communication Technology Economic Policy Uncertainty	ICTi	Five indicators (TEL, MOS, FBS, IIT, ISs) were used by PCA to create the ICT index	WDI
Economic Growth	GDP	GDP per capita constant $2015	WDI
Trade Openness	TO	Services and goods improts and exports (% of GDP)	WDI

This indication was also put out by other researchers as a way to gauge environmental quality. Table 1 shows as description of variables.

d. Model Specification

The basic purpose of this research is to examine that how ecological footprint affected by information & communication technology, FDI, REU, economic growth and trade openness. and, to fulfill our research aim, we follow such investigations. To search for the succeeding equation:

EFP = f(ICTi, FDI, REU, GDP, TO) (1)

Our research investigates the link among ICTi, FDI, renewable energy use, GDP and trade openness on ecological footprint by, the current paper succeeding equation:

$$EFP_{it} = \alpha_{\theta} + \alpha_{1it} ICTI + \alpha_{2it} FDI + \alpha_{3it} REU + \alpha_{4it} GDP + \alpha_{5it} TO + \varepsilon_t \quad (2)$$

The logarithm of independent variables is employed, as majority of studies in the empirical literature. Due to a few data values of ICTi, foreign direct investment, and trade openness being negative, we transform these variables using the following process.

$$y = ln(x + \sqrt{(x^2 + 1)} \quad (3)$$

The final above model after being transformed into linear log form.

$$lnEFP_{it} = \alpha_{\theta} + \alpha_{1it} lnICTI + \alpha_{2it} lnFDI + \alpha_{3it} lnREU + \alpha_{4it} lnGDP + \alpha_{5it} lnTO + \varepsilon_t \quad (4)$$

Here, natural log of ecological footprint is donated as lnEFP per capita hectare. ln ICTi is the natural log of information and communication technology index (TEL, MOS, FBS, ITS and SIS). Natural log of renewable energy is representing as lnREU which is per capita of energy use. lnGDP refers to log of economic growth GDP per capita (constant $2010). Fixed contrary effect is representing as α_{θ}. And time expressed as t (yearly from 1990 to 2018). Error term is referred as ε. Take log of those variable which are measured in percentage is incorrect in econometrics. A variable log represents the growth of a variable (Hakim AliAnalyzing the Link between Distributed Leadership and Teachers' Self-Efficacy Beliefs at Secondary School Level et al., 2021).

e. Panel Unit Root Test

The first thing we checked was whether the indicators are stationary. Scientists applied panel unit root testing, to achieve this goal. In high power circumstances, panel unit root testing performs better than the individual time series analysis. These tests are modified versions of multi-series of unit root analysis for panel, according to. IPS, IM, PESARAN AND SHIN, and LLC LEVIN, LIN AND CHU, are two examples of panel unit root testing, commonly referred to as first generation panel unit root tests. The Im, Pesaran and Shin (IPS) unit root test allows for an individual unit root process whereas, Levin, Lin and Chu (LLC) test assume a joint unit root process, ensuring that pi is consistent between section. By using logarithms, unit root tests conducted to view for stagnations about all the variables. In contrast to H_1, which indicates that unit root is not exist, H_0 represent the presence of a unit root. Equation (5) below illustrates how the LLC and IPS tests behave as expected when using the augmented dickey-fuller (ADF) test:

$$\Delta \boldsymbol{y_{it}} = \boldsymbol{a y_{it-1}} + \sum_{j=1}^{pi} \boldsymbol{\beta_{ji}} \Delta \boldsymbol{y_{it-j}} \boldsymbol{X'_{it}} \boldsymbol{\delta} + \boldsymbol{\varepsilon_{it}} \quad (5)$$

Presumably, it is permissible for the lag orders of different terms to vary across cross sections while keeping the standard α = p -1. The LLC test investigates the following hypothesis:

H_0: p_i: α = 1 (where the unit root is present in the null hypothesis)

H_0: p_i: α < 1 (where the alternative hypothesis lacks a unit root)

Before undertaking unit root testing, first we verified the stability of all of our observables using the LLC and IPS panel approaches. Table (4), summarized the unit root test results. At the level, none of the variables are statistically significant, and the initial difference satisfies the panel unit root. The null-hypothesis cannot refute since all variables fulfil panel unit root

criteria. As a result, the variables are no longer constant. The null hypothesis can be rejected once all the variables have stabilized after passing the initial level.

f. ARDL Bound Test

In term of intercept or trend, show the unrestricted error correction methods utilized in the ARDL bounds test framework in equation 6 and 7. Both the equation, give a framework to perform the ARDL bounds cointegration test. These equations are estimated by using (OLS) ordinary least squares method.

$$\Delta LY_{it} = a_0 + a_1 t + \sum_{i=1}^{m} \alpha_{2i} \Delta LY_{t-i} + \sum_{i=0}^{n} \alpha_{3i} \Delta LX_{t-i} + a_4 LY_{t-1} + a_5 LX_{t-1} + \mu_{1t} \quad (6)$$

$$\Delta LX_{it} = \beta_0 + \beta_1 t + \sum_{i=1}^{m} \beta_{2i} \Delta LX_{t-i} + \sum_{i=0}^{n} \beta_{3i} \Delta LY_{t-i} + \beta_4 LX_{t-1} + \beta_5 LY_{t-1} + \mu_{2t} \quad (7)$$

Δ is the initial different operator and it representing the residual term, which should be well behaved. Expect for α_4 and β_4 are non-coefficients are non-zero. The parameters α_{2i} and α_{3i} indicate the short- and long-term dynamic coefficient respectively. The α_0 and β_0 are drift components, μ_{1t} and μ_{2t} are white noise.

g. ARDL Methodology

Autoregressive Distributed Lag (ARDL) and bound testing techniques are applied in this research. A number of benefits are offered by ARDL method. , noted one of the most significant advantages of ARDL was that it permitted estimate when explanatory variables are endogenous. Endogeneity is also less of a problem as ARDL is free of residual connection. The appropriate lags in endogeneity were demonstrated by. showed that single equation cointegration analysis suffers from endogeneity issues, whereas the dependent and explanatory components can be distinguished using ARDL method., claim that whether the variables are stationary at 1st difference and level / mutually integrated, the ARDL method parameters are asymptotically normal. To analyze the degree of integration several tests like, Augmented Dickay-Fuller (ADF), Phillips-Parron (PP), LLC and IPS are employed in economic literature. It is not necessary presumption that all the variables are integrated in same order. Furthermore, this approach still works, whether the variables are stationary at 1st difference I(0) or level I(I). When there are fewer observations, it is regarded to be better suitable since it is less sensitive to sample size. Here is how our analysis presented the ARDL model.

$$\Delta lnEFP_{it} = \alpha_\theta + \sum_{k=1}^{n} \alpha_{1k} \Delta lnICTI_{(t-k)} + \sum_{k=1}^{n} \alpha_{2k} \Delta lnFDI_{(t-k)} + \sum_{k=1}^{n} \alpha_{3k} \Delta lnREU_{(t-k)} + \sum_{k=1}^{n} \alpha_{4k} \Delta lnBIO_{(t-k)} + \sum_{k=1}^{n} \alpha_{5k} \Delta lnGDP_{(t-k)} + \sum_{k=1}^{n} \alpha_{6k} \Delta lnTO_{(t-k)} + \beta_1 lnICTI_{(t-1)} + \beta_2 lnFDI_{(t-1)} + \beta_3 lnREU_{(t-1)} + \beta_4 lnBIO_{(t-1)} + \beta_5 lnGDP_{(t-1)} + \beta_6 lnTO_{(t-1)} + \varepsilon_t \quad (8)$$

The error term is presented by ε_t. First difference operators are presented by Δ. The (H_I) alternative hypothesis is imposed in place of the null hypothesis (H_0) of cointegration equation (6), which is H_0: $\beta_1 = \beta_2 = \beta_3 = \beta_4 = \beta_5 = \beta_6$ as imposed with alternative hypothesis H_1: $\beta_1 \neq \beta_2 \neq \beta_3 \neq \beta_4 \neq \beta_5 \neq \beta_6$. Additionally, according to, there are two groups of critical regions that are related to upper and lower boundaries for each degree of importance. If the calculated statistical values are more than the upper-limit, and H_0 hypothesis is not accepted, the long-run cointegration connection existences is confirmed. Even yet, if long-run cointegration is not exist, the H_0 hypothesis viable when the estimated statistical value is below the ARDL test lower limit. The cointegration test is declared inconclusive in this case and we are unable to interpret it, because it determined the critical value between these two boundaries.

h. Panel Granger Causality Method

In this study, we will used method to conclude the directional causality among information & communication technology index, foreign direct investment, renewable energy use, economic growth, trade openness and ecological footprint. It has been determined that using this technology is best way to determine and measure causality. To check the causality among the selected factors, Dumitersuc-Hurlin panel causality analysis was carried out. This test is widely accepted, as the advance version of Granger Causality analysis, this test is widely accepted. The test has the advantage of being able to analyze unbalanced panel data, as well as taking into deliberation the continuum and cross sections., suggest that it performs more efficaciously in the existence of slope variation and cross-country vulnerability. This leads to the following is the Dumitresce-Hurlin panel causality equation.

$$Y_{i,t} = a_i + \sum_{k=1}^{K} \lambda_i^k \; Y_{i,t-k} + \sum_{k=1}^{K} \beta_i^k \; X_{i,t-k} + \varepsilon_{i,t} \quad (9)$$

Here, K is the optimal lag interlude, Y & X indicate the factors which are tested for causal link.

4. Results and discussion

a. Descriptive Statistics

Descriptive statistics test was used to determine the normality of the data in this model. Descriptive statistics results are shown in table no. 2.

Table 2: Results of descriptive statistics

	LNEFP	LNICTi	LNREU	LNFDI	LNGDP	LNTO
Mean	0.079095	0.091738	4.024943	0.900146	6.922172	3.773628
Median	-0.172535	-2.292896	4.053606	0.677440	6.854105	4.423682
Max	1.640689	2.249821	4.563514	6.321598	8.410879	5.451484
Min	-0.776647	-0.775095	2.534490	-0.675563	5.869393	-4.023233
SD	0.642809	0.812414	0.442578	0.945780	0.583648	2.325747
Skewness	1.427742	0.951410	-0.974996	2.206652	0.531267	-2.673791
Kurtosis	3.825753	2.318496	3.887229	10.51203	2.695493	8.662144
Jarque-Bera	70.31711	32.51118	36.52593	604.1002	9.722704	482.7247
Probability	0.000000	0.000000	0.000000	0.000000	0.000774	0.000000

Note: Mean, Median and SD are Max, Min and standard deviation respectively.

The empirical findings of mean, median, max, min, standard deviation and skewness are described in descriptive statistics. The mean value of ecological footprint, information & communication technology, renewable energy and foreign direct investment is 0.079095, 0.091738, 4.024943 and 0.900146 respectively. Similarly, average value of economic growth and trade openness

are 6.922172 and 3.773628. The spread or dispersion of values from the mean is measured by the standard deviation. Foreign direct investment standard deviation is more closely related to their respective means. The remaining variables had standard deviation that deviated from their respective means. Therefore, a change in the individual values had a significant impact on the values of the subsequent period. This high level of volatility may make predictions unclear. All the variable appears to fluctuate when the minimum and maximum values are examined. In out observation, the mini, and max values of variables are -0.675563 and 8.410879 respectively.

b. Co-relation Matrix Results

Table 3; shown analyzed variables Co-relation Pearson Matrix. Relationship of all the descriptive variables is illustrates in this table. Significantly different variables have positive and negative relationships with one another. However, the correlation among GDP and ICTi is relatively high which is 0.530134. In other words, we can see that variables correlation is smaller than 0.80. It suggests that there are low chances of multicollinearity issue among the variables being present.

Table 3: Results of Correlation matrix

	LNEFP	LNICTi	LNREU	LNFDI	LNGDP	LNTO
LNEFP	1.000000					
LNICTi	0.190261	1.000000				
LNREU	0.468582	-0.279421	1.000000			
LNFDI	0.050640**	0.162086	-0.231163	1.000000		
LNGDP	0.519795	0.530134	0.120329	0.288740	1.000000	
LNTO	0.353688	0.001538*	0.418620	-0.064488**	0.443995	1.000000

Note: * & ** represents the level of significance at 5% and 10%.

Table 4: Panel Unit Root Results

Variables		LLC	IPS	ADF	PP	Level of Integration
LNEFP	At Level	0.14047	-1.14130	17.2748	23.2182	1(1)
	Significance	0.5559	0.4438	0.2418	0.0568	
	At 1st difference	-6.23265	-6.80553	67.5801	144.406	
	Significance	0.0000	0.0000	0.0000	0.0000	
LNICTi	At Level	-1.08308	1.10985	16.0905	3.22879	1(1)
	Significance	0.1394	0.8665	0.3079	0.9986	
	At 1st difference	-1.43943	-2.51268	34.3203	30.4556	
	Significance	0.0750	0.0060	0.0019	0.0066	
LNREU	At Level	1.15735	1.83782	11.2475	7.17127	1(1)
	Significance	0.8764	0.9670	0.6665	0.9279	
	At 1st difference	-2.00870	-2.66897	28.7641	77.3563	
	Significance	0.0223	0.0038	0.0112	0.0000	
LNFDI	At Level	-1.21527	-2.29607	29.7502	41.0824	1(1)
	Significance	0.1121	0.0108	0.0083	0.0002	
	At 1st difference	-3.84500	-7.52386	79.2748	367.994	
	Significance	0.0001	0.0000	0.0000	0.0000	
LNGDP	At Level	1.07324	2.40578	2.17887	5.70589	1(1)
	Significance	0.8584	0.9997	0.9999	0.9734	
	At 1st difference	-5.13586	-4.44926	46.3193	123.637	
	Significance	0.0000	0.0000	0.0000	0.0000	
LNTO	At Level	-0.97355	0.17696	13.2762	10.7011	1(1)
	Significance	0.1651	0.5702	0.5049	0.7093	
	At 1st difference	-3.66331	-4.66557	46.2589	75.0173	
	Significance	0.0001	0.0000	0.0000	0.0000	

Note: Unit root results of (LLC) Levin, Lin and Chu, (IPS) Im, Pesaran and Shin, Augmented Dickey-Fuller (ADF) and Phillips Perron (PP) represents that the variables sequence passed the test at 1st difference.

c. Results of Unit Root Test

Cointegration those variables which are used in this study are tested before applying the ARDL approach through unit root test. Table 4 presents the result of (lm, Pesaran and Shin W-stat), (Live, Lin and Chu t), (Augumented Dickey-Fuller) and (Phillips Perron) at level and at first difference. All the variables are stationary at 1st difference, according the empirical results of all the unit root tests.

d. ARDL Bound Test Results

The estimated value ARDL bound test is shown in Table 5, the lower and upper bound values are at 1% level of significance (2.880 and 3.990). As a result, the F-Statistic exceeds the upper bound, supporting the rejection of the null hypothesis which means that there is no cointegration among the variables.

Table 5: ARDL Bound Test

Test Statistic	Value	Level of Significance	Bound Test Critical Values	
			I(0)	I(I)
F-Statistic	90.26793	1%	2.880	3.990
		5%	2.270	3.820
		10%	1.990	2.940

Null Hypothesis: No log-run relationship exists.

e. Long-Run and Short-Run Panel-ARDL Results Estimation

The panel ARDL results of long and short-term shown in Table-6. Penal-ARDL in Long Run results show that where the coefficient of ICTi is negative which reveals that 1% addition in ICTi will reduce the ecological footprint by (0.028184). However, information & communication technology contribute control to ecological footprint in South Asian nations. Moreover, 1% increase in REU will also increase EFP (0.077905) and coefficient value of renewable energy show significant and negative impact on ecological footprint. Nevertheless, foreign direct investment shows significant and positive impact on ecological footprint in the long-term, if FDI increase 1% will increase ecological footprint (0.008453). Likewise, GDP shows positively significant results on EFP. Moreover, if 1% increase in GDP will increase ecological footprint (0.521602). The findings show that trade openness has invers impact on EFP, this indicates that 01% rise in TO will reduce EFP (0.004707). Error correction term (ECM) is -0.439 which is statistically significant and negative, table no. 6 demonstrates the speedy adjustment to the long-run equilibrium as well as the consolidation of the equilibrium relationship between the variables. It further clarifies that, after correcting the short-run disequilibrium, our model returns to long-run equilibrium at a rate of adjustment of 43%. In short-run the ecological footprint is presented in two shocks negative and positive, the results of ecological footprint in short-run are insignificant (Rahman & Bakar, 2019).

Table 6: Estimated Panel-ARDL (3,0,0,0,0,0,0) Model Results

Variables	Coefficient	Std. Error	T. Statistic	Prob.
		Long-Run Results		
LNICTi	-0.028184*	0.005872	-4.799407	0.0000
LNREU	-0.077905***	0.004654	1.816103	0.0712
LNFDI	0.008453*	0.025590	-3.044356	0.0027
LNGDP	0.521602*	0.022233	23.46023	0.0000
LNTO	-0.021824*	0.004707	-4.636879	0.0000
C	-2.935711*	0.214641	-13.67728	0.0000
		Short-Run Results		
ECT	-0.439398**	0.208790	-2.104501	0.0368
Δ(LNEFP(-1))	-0.042347	0.084933	-0.498593	0.6187
Δ (LNEFP(-2))	0.010814	0.093690	0.115428	0.9082
Δ(LNICTI)	-0.016733	0.033209	-0.503885	0.6150
Δ(LNREU)	-0.567175	0.162213	-3.496491	0.0006
Δ(LNFDI)				
Δ(LNREU)	-0.201216	0.168470	-1.194371	0.2339

Null Hypothesis: *, ** and *** indicate the significance level at 1%, 5% and 10% respectively.

f. Granger Causality Results

Table 7 presents the Granger Causality analysis of selected variable and control variables of this study. We found that there is no causality among ICTi and EFP. On the other hand, this implies that bidirectional causality among FDI, GDP and EFP. We also find unidirectional causality among REU, TO and ecological footprint. However, FDI, GDP and EFP have bidirectional causality (Ur Rahman & Bakar, 2018).

Table 7: Granger Causality Results

Null Hypothesis	Obs.	F-Statistic	Prob.
LNICTi does not Granger Cause LNEFP	182	1.38230	0.2498
LNEFP does not Granger Cause LNICTi		0.26061	0.8537
LNFDI does not Granger Cause LNEFP	182	4.53132	0.0044*
LNEFP does not Granger Cause LNFDI		0.04910	0.9856
LNREU does not Granger Cause LNEFP	182	6.62956	0.0003*
LNEFP does not Granger Cause LNREU		2.16586	0.0938***
LNGDP does not Granger Cause LNEFP	182	3.10165	0.0283**
LNEFP does not Granger Cause LNGDP		1.06640	0.3650
LNTO does not Granger Cause LNEFP	182	2.75156	0.0442**
LNEFP does not Granger Cause LNTO		2.45547	0.0647

Note: Null Hypothesis reject at 1%, 5% and 10% level of significance *, **, ***.

5. Conclusion and Policy Recommendations

The South Asian nations have promoted economically, the ever-increasing trends in their environmental factors have create a concurrence between the researchers to ensure environmental quality. Our study aims is examine interplay of information & communication technology (index), renewable energy use, foreign direct investment, economic growth and trade openness on ecological footprint in South Asian economies. The study framework for panel data of six South Asian countries, from (1990-2018). First of all, the unit root test and co-relation integration test are analyzed between the variables in this research. Finally, panel ARDL and Granger causality methods are used to examine the long-run and short-run association among the variables in this study. This is the empirical findings of this study can be summarized as follows: i) this study discovered that the EKC and PHH hypothesis exists in South Asian nations. ii) conclusion of this study conducted that FDI, and economic growth cause an increase in ecological footprint. iii) use of ICTi, REU and trade openness reduce the EFP impact.

According to the empirical results, information & communication technology has a favorable relationship with ecological footprint. First, the fact that information & communication technology have a negative relationship indicates that information & communication technology improving the environmental conditions in South Asian nations. Second, consider there is negative effects of renewable energy use and ecological footprint in South Asian economies which results decreasing environmental degradation. This study suggests that stakeholders implement a system that can assess companies that produce goods using renewable energy sources. Our findings are similar with. Thirdly, there is a positive association of foreign direct investment and economic growth on ecological footprint, which results an increase in environmental degradation. Wise else, our findings explore that trade openness has opposite association with EFP, it means that trade openness decreasing environmental degradation. Our findings are similar with (Shahzadi, Ali, et al., 2023, Hafiza et al., 2022).

The conclusions of this article have important ramifications for investors, administrators, governments and individuals. The primary goal of every nation in the global world is to achieve high economic growth, however, when setting growth targets, the South Asian countries should receive special consideration. Therefore, certain required efforts should be done to formulate policies they would aid in achieving GDP, at the same instant lessen or at the very least not contribute to the further destruction of the environment in South Asian countries. Our findings demonstrated how Information & communication technology development improves environmental sustainability. Therefore, in order to reap the benefits of increased industrial production while also reducing ecological footprint, our research strongly encourages the South Asian economies to constantly upgrading and redesigning their information & communication technology framework. Information and communication technology development is typically linked to implementing more environmentally friendly, cutting edge, renewable and clean practices. Thus, the inverse relationship among renewable energy and ecological in South Asian Nations, this study advises stakeholders to implement a system that can monitor businesses that produce goods using renewable sources.

Therefore, the suggested strategy can aid in setting a specific goal for business adopting renewable energy. Additionally, governments in these economies need to set aside adequate money in their budgets for REU, such as biofuel energy, biomass energy, hydropower and wind power. The public can be made aware of the value of adopting more and more renewable energy resources by the government and policymakers. In all the economies of this study, the findings corroborate the contamination have hypothesis implying that foreign direct investment pollutes the environment by brining ecologically unfavorable technologies. However, to improve the environmental standard and reduce the negative impact of FDI, more stringent laws and strategies should be introduced that are more environmentally sustainable and promote FDI. Furthermore, the policymakers should not only promote rules and regulations, but also strictly compliance the policies to control the environmental deterioration.

This study provides valuable insights, but important gaps were also identified. To fulfill the gap, future researcher should focus on. Because there was no data available for all the South Asian economies, extrapolating the results to all economies could lead to an inflated conclusion. Other important variables influencing ecological footprint such as good governance, green energy, green technology, regulatory quality and human capital, were not included in this research model. Furthermore, in order to examine the effect of features on pollution in other jurisdictions future studies used interaction variables such as globalization.

APPENDIX

Fig.1: Measuring the Information Society Report Volume-I (2018) Source: (World Information & Communication Technology Development), (2005-2018)

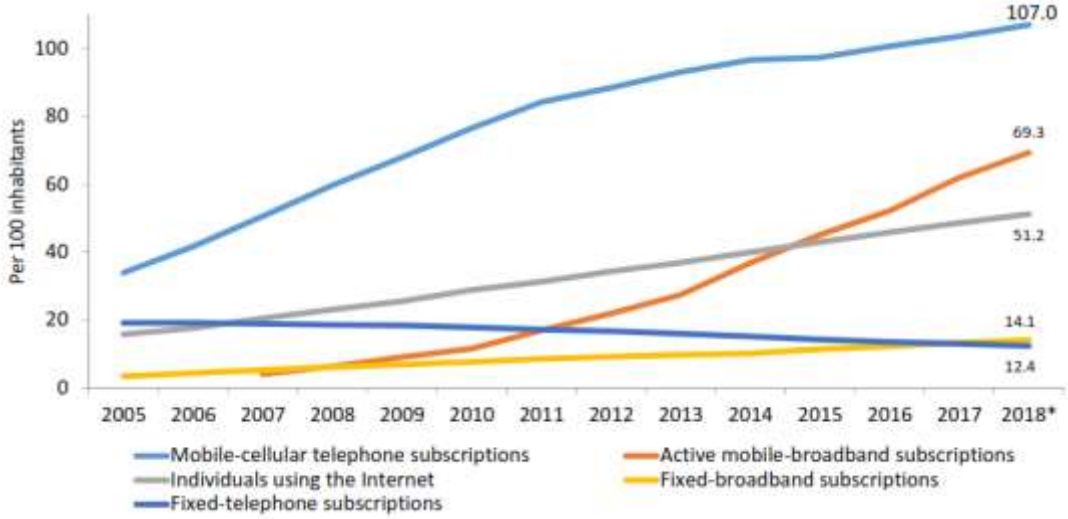
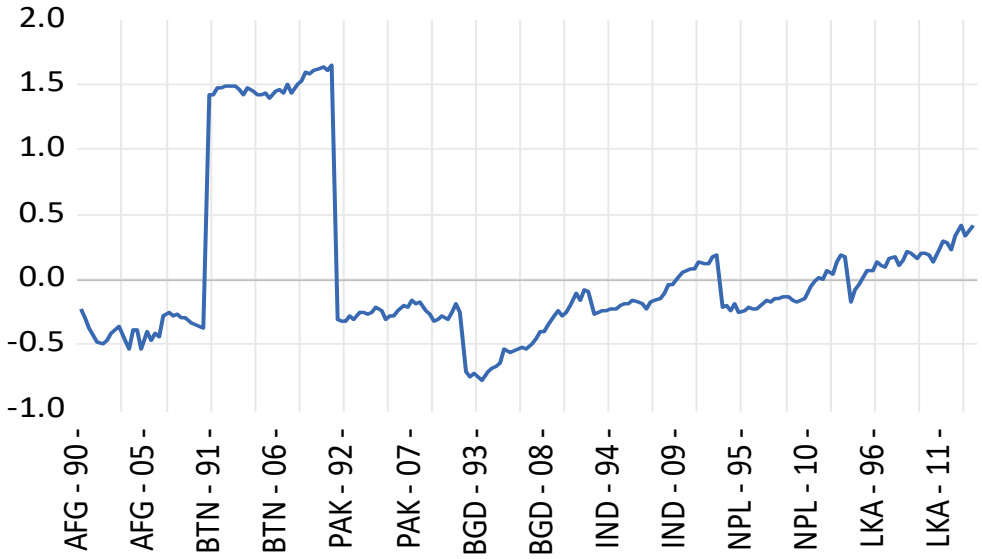
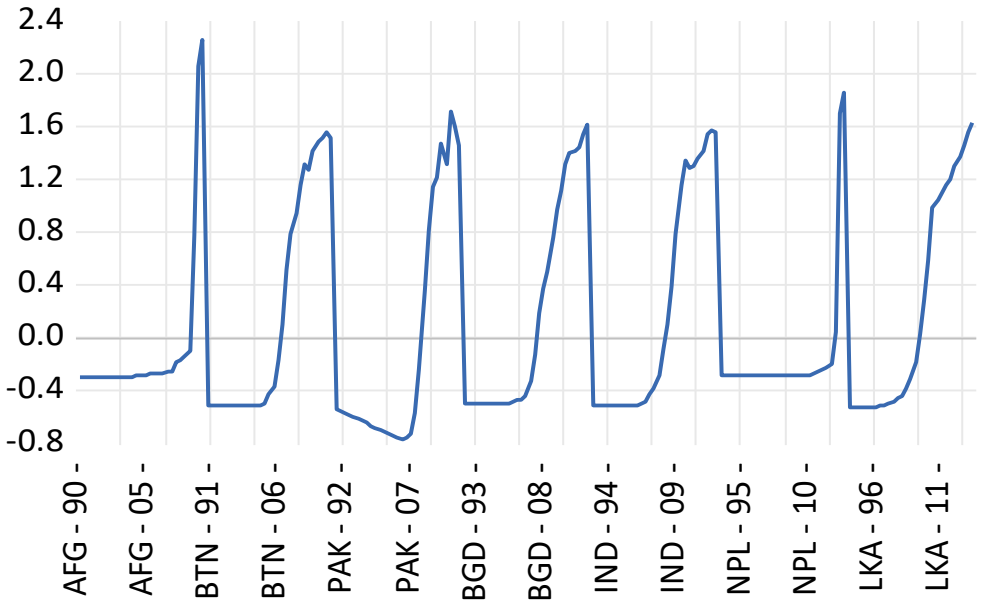


Fig 2: Granger Causality Graphs

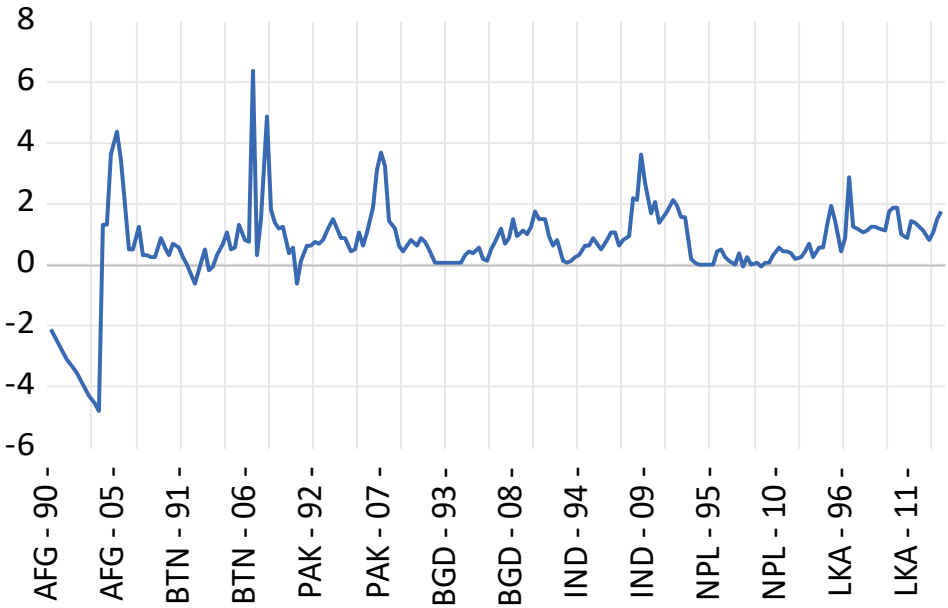
LNEFP

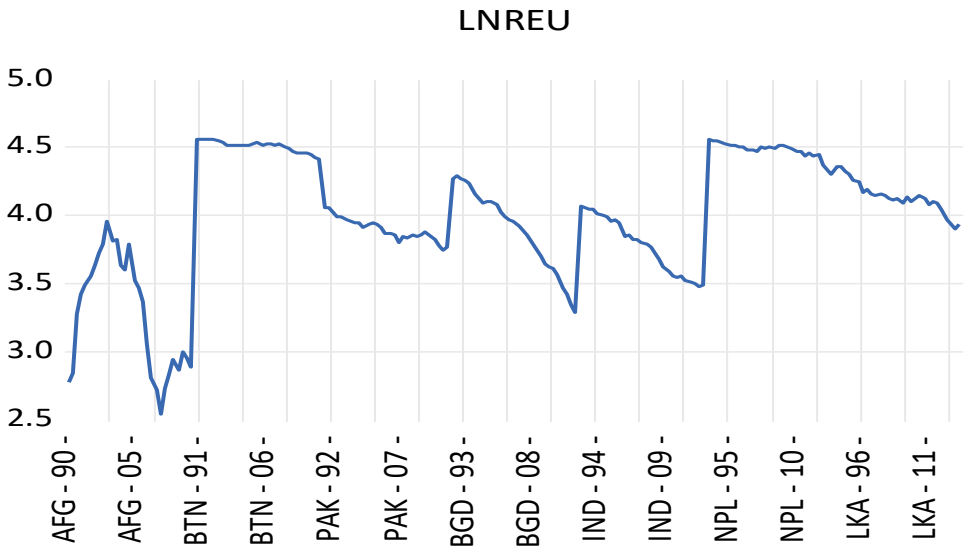


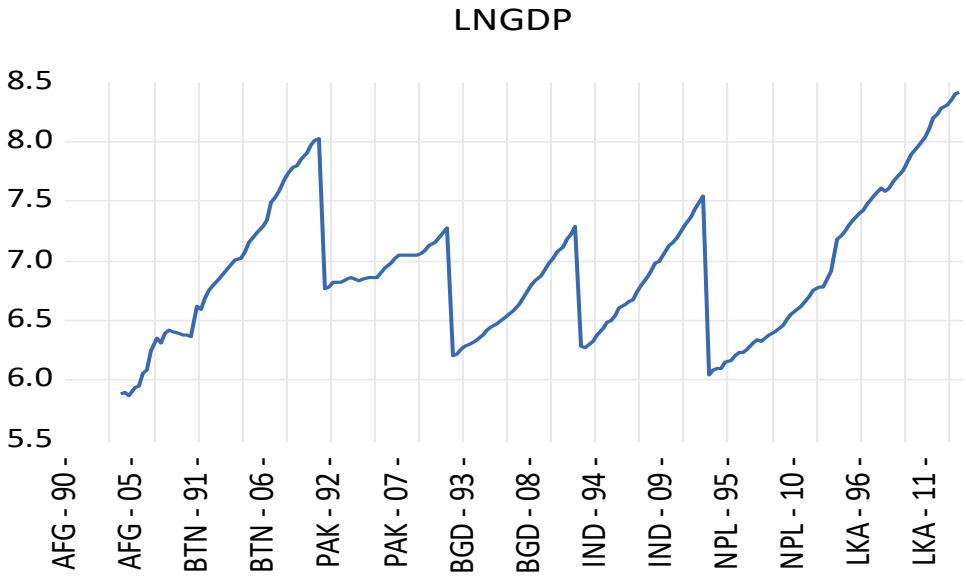
LNICTI

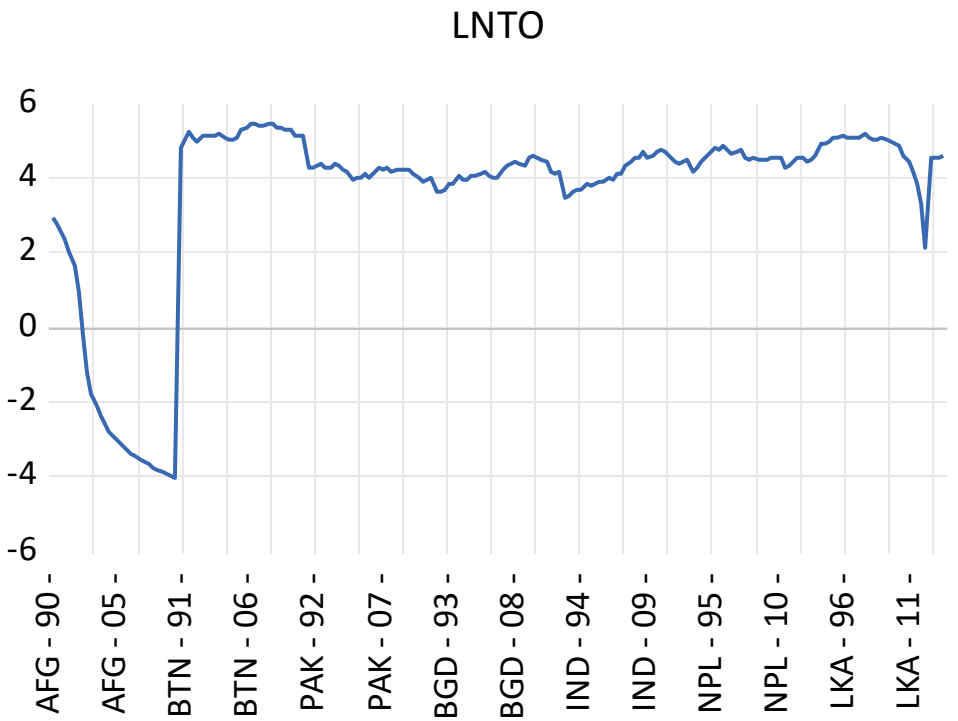


LNFDI









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