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Exploring the Drivers of Greenhouse Gas Emissions in Pakistan: The Role of Deforestation, Urbanization, and Economic Growth

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ABSTRACT

This study examines the relationship between deforestation and greenhouse gas (GHG) emissions in Pakistan, with a focus on the roles of urbanization, financial development, and economic growth. Using data from 2001 to 2023, the study employs an Autoregressive Distributed Lag (ARDL) bound testing approach to examine the short- and long-run dynamics of these variables. The results indicate that urbanization and GDP significantly increase CO_2 emissions, while deforestation has a negative short-run impact with minimal long-run effects. The study emphasizes the importance of implementing effective environmental policies, including environmental taxes and market-based strategies, to reduce greenhouse gas (GHG) emissions and mitigate the ecological impacts of deforestation.

Keywords: Deforestation, CO_2 Emissions, Urbanization, Financial Development, Economic Growth, ARDL
JEL Classifications: Q56, Q54, R11, C32

1. INTRODUCTION

Forests are among the natural ecosystems that control and influence a region's weather, climate, and atmospheric greenhouse gases (GHG). At least 25% of global greenhouse gas (GHG) emissions are caused by deforestation and forest degradation, which makes them a significant contributor to climate change and increases the hazards of vulnerable groups from climate stressors such as flooding (Johnson and Alila, 2023), heat waves, and others. In this context, the Glasgow Leaders' Declaration on Forests and Land Use, which seeks to halt deforestation and land degradation by 2030, is driven by the urgent need to address these environmental challenges (UN, 2021). To achieve this worldwide goal, market-based solutions can be crucial. Research and experimentation on market-based interventions to stop and reverse deforestation and forest degradation have so far concentrated on creating and expanding carbon offset markets, which enable organizations that face high GHG emission reduction costs to fulfill their voluntary or compliance requirements by funding less expensive forestry projects that lower GHG emissions from that industry (West et al., 2023). One of the primary sources of these offsets is the United Nations Reducing Emissions from Deforestation and Forest Degradation (REDD+) initiative, which aims to produce several co-benefits for sustainable development. However, REDD+ and other forest carbon offsets have come under heavy fire for not slowing deforestation or providing significant, lasting, and meaningful emissions reductions (Haya et al., 2023; West et al., 2023). Furthermore, New Zealand, which has included specific GHG emissions linked to deforestation in its emissions trading scheme, is testing another market-based strategy. Forestland owners are held accountable under that program for deforestation-related emissions from forestlands that are permanently cleared, as well as those who receive compensation for storing and sequestering carbon (Carver et al., 2022). However, the initiative does not address GHG emissions from industrial logging operations that do not entail forestland conversion. Payments for ecosystem services programs (PESPs) that incorporate a forest carbon component are one type of subsidy available to forestland owners, as are other market-based strategies (Le et al., 2024).

Another market-based strategy that hasn't gotten much attention is the imposition of carbon fees on GHG emissions from logging operations. Despite new data showing a negative and statistically significant correlation between environmental (Pigouvian) taxes and CO_2 emissions, the World Bank has identified a global deficiency in their use (Wolde-Rufael and Mulat-Weldemeskel, 2023). Many economists believe that they are the best solution to the issue of harmful externalities, and they are also a direct application of the polluter pay principle, protect and restore tropical forests, or improve sequestration (Barbier and Burgess, 2020). Natural disasters, including hurricanes, fires, and droughts, can destroy forests. However, human activity is the leading cause of deforestation. Both the environment and human life are severely harmed by deforestation. The loss of biodiversity is one of the main consequences of deforestation, as it leads to the extinction of innumerable species of vegetation and animals by destroying their habitats. Furthermore, soil erosion brought on by deforestation can result in landslides and water source contamination. It contributes significantly to climate change as well. Because they absorb a lot of gases such as carbon dioxide and other greenhouse gases, forests are essential carbon sinks. Global warming is exacerbated when forests are removed because the carbon stored in their tissue is released into the sky. The stability of the environment is disturbed, and temperatures rise due to the spikes in greenhouse gases. Among the most severely impacted are primary forests, home to the world's oldest and largest trees. The loss of primary forests is particularly detrimental to biodiversity worldwide since these forests are essential for the survival of rare and endangered species. One of the leading causes of environmental degradation is deforestation for agriculture and development. The land used for agriculture has almost doubled in the past century. Due to deforestation, millions of hectares of tropical forests are lost yearly in South and Central America, Southeast Asia, South Asia, and Africa. For instance, less than 5% of Pakistan's land is covered by forests, making it a low-forest country. Deforestation continues rapidly, reaching a peak of 0.306% in 2000. Large-scale agricultural expansion is mostly to blame for Pakistan's deforestation, with logging, land conversion, and firewood gathering remaining recurring problems. International accords concerning the Reduction of Emissions from Deforestation and Forest Degradation (REDD+) are another commitment made by the country. Deforestation still occurs in the Margalla Hills, a natural reserve park with distinctive biodiversity (Batool et al., 2016). According to the Worldwide Fund for Nature-Pakistan (WWF-P), Pakistan continues to lose around 11,000 hectares of forests annually as a result of land conversion for commercial, residential, and agricultural projects, wildfires, and climate change.

However, the current study tries to identify the impact of deforestation on greenhouse gas (GHG) emissions, exploring the interactions with financial development, urbanization, and GDP from 2001 to 2023 in Pakistan. It also assesses the effectiveness of environmental taxes in mitigating emissions. The study employs an Autoregressive Distributed Lag (ARDL) model with the Bound testing approach to address the abovementioned relationships.

However, the study noticed that Urbanization, GDP, and financial development all significantly positively impact CO_2 emissions in both the short and long run. However, deforestation shows an adverse short-run effect with minimal long-run influence. The model indicates a stable long-run equilibrium, with urbanization and GDP as the primary drivers of emissions over time.

This article is designed as follows: Section 2 describes the literature review. Section 3 describes the theoretical framework, model selection, data, variable definitions, and econometric methodology. Section 4 presents the results, discussion, and policy implications. The last section, section 5, presents the conclusions.

2. LITERATURE REVIEW

One of the most urgent problems in the world is climate change, which is mostly caused by human-produced gases such as carbon dioxide and other greenhouse gas (GHG) emissions. Methane, nitrous oxide, carbon dioxide, and several synthetic compounds are examples of greenhouse gases. Heat is retained in the atmosphere due to these gases' ability to absorb some of the energy that the Earth emits. The equilibrium between the acquired solar energy and Earth's emitted energy is upset by this extra heat, which affects weather and atmospheric conditions globally and regionally (NASA, 2016). Carbon dioxide (CO_2) emissions, the primary cause of greenhouse gas emissions, increased by 8.9% annually from 3.5 billion tons in 1920 to 35.2 billion tons in 2020 (WDI, 2025). The biggest overall increase in CO_2 emissions in several global north countries happened between 1900 and 1950, especially in North America, when the U.S. and Canada had increases of 238% and 647%, respectively. Between 1950 and 2000, total emissions increased, although at slower rates (268% in Canada and 137% in the United States) (IEA, 2023; World Resources Institute, 2025). When the Intergovernmental Panel on Climate Change (IPCC) issued its first assessment report in 1990, it warned that human activity-induced emissions had dramatically raised GHG concentrations. This prompted calls for an international agreement, and the UN Framework Convention on Climate Change was adopted in 1992 during the Rio de Janeiro Earth Summit in Brazil (IPCC, 2023). The Kyoto Protocol, the inaugural agreement to set legally enforceable GHG emission reduction objectives for industrialized nations, was adopted in 1997 due to additional discussions to tighten the commitments. This resulted in those nations reducing their emissions. The 21st Conference of the Parties (COP 21) Paris Agreement in 2015, which mandated that industrialized and less developed nations contribute to emissions reductions by 2020, was made possible by the Doha Amendment, which extended the Kyoto commitments until 2020 (United Nations, 2022). In addition to an agreement on an increased transparency structure to govern emissions reporting, the Rules of Procedure for the regionally determined commitments to reduce emissions were concluded at the COP26 (United Nations, 2021). Moving forward to achieve climate promises was a major focus of the most recent COP27, which took place in Sharm el-Sheik, Egypt, in 2022 (United Nations, 2022). Canadians are aware of the nearly universal agreement that climate change poses an important threat to the welfare of humans, the economy, and overall well-being. Since all political parties agree that human activity is a major contributor to climate change, environmental protection has been established as a critical issue in Canada. This is demonstrated by the fact that the topic was at the core of the two most recent federal elections (Reid, 2021). The 2006 Clean Air Regulatory Agenda, which established reduction targets for particular industries (Environment Canada, 2006), the federal government's 2019 plan to outlaw certain single-use plastics, and the 2019 Pan-Canadian Framework on Clean Growth and Climate Change carbon pricing policy (Canada, 2017) are just a few of the policies that Canada, like many other nations, has put in place to reduce anthropogenic greenhouse gas (GHG) emissions. The greenhouse gas (GHG) output to GDP ratio remains relatively high despite Canada's policy initiatives, suggesting room for improvement in fulfilling its goal under the 2016 Paris Agreement (Ajmi et al., 2015).

The fact that both the federal and provincial levels of governance have jurisdiction over several environmental domains presents difficulty in the effective and efficient implementation of policy in Canada (Becklumb, 2013). It has resulted in some variation among provinces. For example, even though environmental protection is widely supported in Canada, some provincial authorities have fought hard against stricter regulations and carbon pricing, even going so far as to challenge the federal government's constitutional authority for implementing it in the Supreme Court of Canada 1 (Ecofiscal Commission, 2019). There is a reciprocal relationship between GDP growth and carbon emissions; rapid economic expansion can raise resource consumption and output, which raises carbon emissions. According to Dietz et al. (2007), these substantial carbon emissions have the potential to worsen environmental issues like climate change, which can impact economic growth. Economic growth becomes a driver of carbon emissions because nations concentrate on developing economies that promote higher production activity regardless of their impact on the environment, according to research by Sheraz et al. (2022). Rather, Dong et al. (2020) suggest that the link is negative. The authors discovered that elements including clean energy investment, stringent environmental regulations, and heightened public knowledge of environmental issues can decrease carbon emissions. When the economy expands beyond a certain point, it strives for technical improvement, resulting in pollution management (Shahbaz and Sinha, 2019). Human capital is frequently associated with carbon emissions. However, several scientists contend that the loss of human capital is the reason for the uneven climate change results (Sheraz et al., 2021). By promoting production units and industrialization levels, the majority of less developed nations boost economic activity to alleviate severe poverty and attain greater economic growth (Khan and Yahong, 2021). The key to raising economic activity, which will raise economic growth and lessen the severity of severe poverty, is promoting and speeding up industrialization (Khan et al., 2021). Additionally, this procedure degrades the natural world (Islam and Ghani, 2018). According to Zafar et al. (2019), who looked at the impact of industrialization on environmental pollution in 46 Asian countries, industrial output is the main source of CO_2 emissions. They saw how industrialization significantly and favorably affected carbon emissions. However, Jiang and Ma (2019) discovered that industry has contributed to reducing the impact of carbon emissions because businesses typically prefer to fund technological innovation rather than scale expansion, and governments favor the growth of green finance, which leads to more funding for environmental protection projects. According to the findings of the Khan and Yahong (2021) study, they were unable to identify a value-added proportion of GDP that was statistically significant for industrial influence. Even if the growth of the financial sector has significant implications for environmental degradation, prior studies have mostly overlooked financial development in addition to the causes mentioned above (Habiba et al., 2021). The effects of various financial development metrics on environmental deterioration vary (Yao and Tang, 2021). For successful green structural change, the financial sector is crucial in providing the required investments in low-carbon technologies (D'Orazio and Dirks, 2022). Therefore, expanding the nation's energy business through sufficient financial aid has been one of the primary policy alternatives used by multiple governments since 1994 to prevent environmental harm (Haseeb et al., 2018).

The evolution of climate-related economic policies in recent decades presents a more nuanced picture that requires analysis. First, the use of environmental adaptation and mitigation techniques about the creation of green technologies, whose spread is constrained by several obstacles, including price, a lack of expertise and understanding, market structure, and a lack of funding. Second, compared to non-green innovation, green innovation is riskier and necessitates long-term financial resources (Mazzucato and Semieniuk, 2018). Third, even if there have been encouraging developments in green finance in the past decade, the flow of funds is not enough to close the gap in green finance. According to a study conducted in India by Goswami et al. (2023), urbanization, trade openness, and energy consumption all had long-term positive correlations with CO_2, although carbon dioxide emissions and economic growth had a negative correlation at the prior lag.

Raihan (2023) examined the relationship between CO_2 emissions, tourism, forest area, industrialization, urbanization, productivity from agriculture, economic growth, and the usage of renewable energy in the Philippines. The findings indicated that a 1% rise in economic growth, growth in industry, growth in cities, and tourism led to increases in CO_2 emissions of 0.16%, 0.06%, 1.25%, and 0.02%, respectively. There is some debate surrounding the concept of monitoring and controlling greenhouse gas emissions from industrial logging operations. Since whatever is released is eventually reabsorbed by new growth, many contend that wood products for bioenergy or building materials are carbon neutral in terms of biogenic carbon. They also contend that wood products are less energy-intensive than many alternatives and should be promoted as part of climate policy (Hoxha et al., 2020). Therefore, tabulating or regulating GHG emissions from logging is unnecessary. Piłatowska et al. (2020) investigated whether nonlinearities exist in the current connection within the Spanish environment. Their results show that nuclear power has a moderating influence on CO_2 emissions throughout the expansion era. Therefore, the authors concluded that nuclear energy significantly improves air quality. Additionally, the Vo et al. (2020) study provides strong evidence for the importance of nuclear energy and alternatives to fossil fuels in successfully tackling CO_2 emissions problem in nearly all the Progressive Agreement for Trans-Pacific Partnership (CPTPP) countries. Furthermore, the study shows that trade liberalization is essential for promoting a decrease in greenhouse gas emissions. In their study, Jahanger et al. (2023) investigated the temporal effects of atomic energy on carbon emissions in the top nuclear-producing countries using moments quantile regression methods. The data used for the analysis covered the years 1990-2017. Because of its ability to efficiently reduce CO_2 emissions across all quantiles, nuclear energy is a competitive and sustainable substitute for traditional fossil fuels. The results strongly support the EKC hypothesis and confirm the inverse association between CO_2 emissions and quadratic economic growth (GDP squared). Sadiq et al. (2023) studied carbon emissions, nuclear factor B energy, globalization, and technical innovation among the top ten nations with the largest nuclear radiation consumption between 1990 and 2017. The study also addressed economic growth and the exploitation of sustainable energy sources. The results show that cutting CO_2 emissions is a practical way for nuclear power and technological developments to save costs while protecting the environment.

Another widely held belief is that conversion of natural forests to plantations is not a significant concern concerning forest carbon management because intensively managed forestlands are better at sequestering carbon than older forests (Ameray et al., 2021). According to Matar and Elshurafa (2017), Saudi Arabia's cement sector is the primary source of CO_2 emissions. The authors contended that an initial carbon price may reduce CO_2 emissions regardless of choice. In contrast, Kang et al. (2022) examined the effects of CO_2 and energy reduction on Korea's economic growth and industrial efficiency. The GDP decreased by 0.1% for every 1% decrease in CO_2. This suggests that nations must implement reasonably priced carbon-neutral measures to improve environmental quality and avoid harming their economies. Regarding emerging nations, an examination of data from 1986 to 2018 in Uganda revealed that, whereas GDP grew, CO_2 and energy consumption did not (Otim et al., 2022). Fossil fuel consumption and urbanization raised CO_2 in Kenya, indicating the necessity for the development of renewable energy technology (Otim et al., 2023). A South African study shows a substantial negative correlation between emissions and energy use (Kareem et al., 2023). Due to differences in energy sources, amounts, and usage patterns, emissions are impacted by energy consumption in undeveloped sectors like agriculture and urbanization (Yahya and Lee, 2023). Yang et al. (2023) examined how China's CO_2 emissions were affected by energy intensity, industrial change, and economic growth from 1980 to 2019. The findings showed a U-shaped nexus for cointegration of all the variables. Furthermore, CO_2 emissions were significantly reduced by the intensity of energy and the second-generation added value. Road infrastructure, energy consumption, and economic growth contributed to Indonesia's rising CO_2 emissions, indicating the need for an energy-efficient transportation system and renewable energy (Yahya and Lee, 2023).

2.1. Research Gap

Climate change, driven by human-induced greenhouse gas emissions, has led to global efforts to reduce CO_2 emissions levels through international agreements such as the Paris Agreement and the Kyoto Protocol. Studies highlight the link between economic growth, urbanization, and emissions, with clean energy investments and green innovation mitigating these effects. However, the role of deforestation in this context remains underexplored, particularly in countries like Pakistan. Previous research has focused on industrialization and energy consumption, but the interaction of deforestation with GDP and financial development in Pakistan is still unclear. This study aims to fill this gap by examining these dynamics from 2001 to 2023.

2.2. Problem Statement

Managing greenhouse gas (GHG) emissions is made more difficult by the SAARC countries' rapid urbanization, changing financial systems, and changing environmental regulations. Despite being a catalyst for economic expansion, urbanization has been connected to worsening ecological conditions by increasing greenhouse gas emissions. Environmental taxes can alter the link between financial development and GHG emissions. Determining whether urbanization and GHG emissions in these nations have an inverted U-shaped (Environmental Kuznets Curve) relationship is essential. This study is novel because it incorporates factors that haven't been examined before, such as the relationship between environmental taxes and financial development, urbanization, and deforestation. In particular, how SAARC countries' forest areas affect their CO_2 emissions has not been thoroughly investigated, nor has the relationship between energy use and urbanization been examined as an explanatory factor. By offering evidence-based suggestions to reduce GHG emissions and advance sustainable development successfully, this thorough analysis seeks to close these gaps.

2.3. Research Objectives

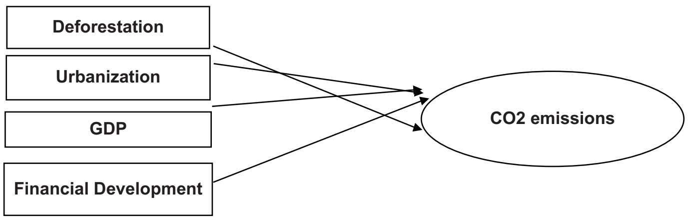
i. To examine how deforestation affects environmental deterioration in Pakistan, specifically through greenhouse gas (GHG) emissions
ii. To assess how Pakistan's financial development and deforestation interact to affect GHG emissions
iii. To assess how Pakistan's GHG emissions are affected by urbanization and how it interacts with deforestation
iv. To assess how GDP affects GHG emissions in Pakistan and how it interacts with deforestation
v. To investigate how deforestation affects Pakistan's GHG emissions and how well environmental taxes work to reduce them
vi. To suggest evidence-based policy actions to lower GHG emissions that are based on the study's conclusions.

2.4. Research Hypotheses

H_1: Higher CO_2 emissions from agriculture are positively associated with increased deforestation rates.

H_2: Rapid urbanization leads to higher deforestation due to increased demand for land and infrastructure development.

2.5. Conceptual Model



H_3: Higher GDP levels are associated with increased deforestation in the short run, but this relationship may reverse at higher income levels (following the Environmental Kuznets Curve hypothesis).

H_4: Greater financial development contributes to deforestation by enabling more investment in land-intensive economic activities.

H_5: The combined effect of CO_2 emissions from agriculture and urbanization exacerbates deforestation more than their individual effects.

3. DATA, MODEL, AND METHODOLOGY

3.1. Data

This study aims to investigate the impact of macroeconomic factors on economic and environmental outcomes. This paper specifically examines the contributions of financial development, urbanization, deforestation, gross domestic product, and greenhouse gas emissions (CO_2). Annual data and information from global databases spanning multiple years are utilized. The annual data for Pakistan from 2001 to 2023 is used in this analysis. Table 1 below provides an overview of all the study variables, the units of measurement, the data sources, and the symbols utilized in the analysis.

3.2. Model Specification:

For the model to successfully illustrate the primary goal of our study, the following functional structure has been constructed:

$$CO_2 = f(Urb, Def, GDP, FD) \quad \text{(i)}$$

Reviewing the past literature and following the study, the linear econometric form of the above model is as follows:

$$CO_{2t} = \alpha_0 + \alpha_1 U_r b_t + \alpha_2 Def_t + \alpha_3 GDP_t + \alpha_4 FD_t + \varepsilon_t \quad \text{(ii)}$$

Table 1: Variables of the study and their description

Variables	Symbol	Unit	Source
Greenhouse gas emissions	CO_2	CO_2 emissions (mt per capita)	GCB
Deforestation	Def	Forest area (% of land area)	WDI
Urbanization	Urb	Urban population growth (annual%)	WDI
Gross domestic product	GDP	GDP per capita (current US$)	WDI
Financial Development	FD	Index	IMF

The coefficients of the explanatory variables in the equation above are α_1, α_2, α_3, and α_4 whereas the intercept is α_0. The error term is denoted by ε, and the subscript t explains the time. The following equation can be obtained by taking the natural logarithm of the two-sided variables:

$$lnCO_{2t} = \alpha_0 + \alpha_1 lnUrb_t + \alpha_2 lnDef_t + \alpha_3 lnGDP_t + \alpha_4 lnFD_t + \varepsilon_t \quad \text{(iii)}$$

3.3. Econometric Methodology

3.3.1. Unit root

This study establishes stationarity of the time-series data and separates stochastic trends from non-stationary processes using the Augmented Dickey-Fuller (ADF) (Dickey and Fuller, 1979) and Phillips-Perron (PP) (Phillips and Perron, 1988) unit root tests. These tests help determine whether the variables require differencing to become stationary or if they are still at level. When employing the ARDL model to perform reliable statistical tests, this step is required.

3.3.2.ARDL model

There are several methods for identifying short- and long-term interactions and testing for cointegration. This study employs Autoregressive Distributed Lag (ARDL) Bounds Testing strategy (Pesaran et al., 2001), which offers several advantages over alternative cointegration methods. These consist of: (a) the capacity to determine long-term relationships between variables integrated at various levels, I(0), I(1), or a combination of both; (b) its suitability for single-equation models; (c) its adaptability to small sample sizes; (d) the freedom to choose the best lag lengths for each variable; and (e) the estimation of both short-term dynamics and long-term relationships using the Error Correction Model (ECM) built into the ARDL framework. The ECM captures short-term and long-term effects; the other coefficients represent short-term adjustments, while long-term causation is shown by a negative and statistically significant error correction term (ECT < 0). Information criteria like AIC, SC, or HQ are used to find the ideal lag structure to guide the model selection process. A long-run relationship is confirmed if the F-statistic from the limits test exceeds the upper bound; if it falls between the bounds, the result is equivocal; and if it goes below the lower limit, there is no evidence of cointegration.

$$\begin{aligned}\Delta lnCO_{2it} &= \alpha_0 + \sum_{i=1}^{p} \alpha_1 \Delta lnCO_{2it-i} + \sum_{i=1}^{p} \alpha_2 \Delta ln\text{Urb}_{it-i} \\ &+ \sum_{i=1}^{p} \alpha_3 \Delta lnDef_{it-i} + \sum_{i=1}^{p} \alpha_4 \ \Delta\text{lnGDP}_{it-i} \\ &+ \sum_{i=1}^{p} \alpha_5 \Delta lnFD_{it-i} + \beta_1 lnCO_{2it-1} + \beta_2 ln\text{Urb}_{it-1} \\ &+ \beta_3 lnDef_{it-1} + \beta_4 lnGDP_{it-1} + \beta_5 lnFD_{it-1} + \mu_t \quad \text{(iv)}\end{aligned}$$

The terms with summation signs represent the short-term error correction form, while the terms with β represent the long-term equilibrium between the variables. The Akaike Information Criterion (AIC) is used to calculate the maximum lag lengths ρ, ρ1, ρ2, and ρ3, and t-i is the best lag selection based on this criterion. In contrast to other approaches, the bounds testing strategy provides upper and lower bounds for various designs and significant F-statistic values. Therefore, any F-statistic value below the lower bound indicates no co-integrating relationship between the variables. Therefore, any F-statistic value below the lower bound indicates no co-integrating relationship between the variables. Conversely, a long-term association is present if the F-statistic is higher than the F (upper bound). It should be noted that test results cannot be generalized if the F-statistic falls between the top and lower boundaries.

3.3.3. Diagnostic model

Diagnostic tests utilize key assumptions to evaluate the robustness and efficacy of the ARDL model. A set of residuals' serial correlation can be examined using the Breusch-Godfrey Lagrange multiplier (LM) (Breusch, 1978) test, and the errors' normality can be ascertained using the Jarque-Bera (Jarque and Bera, 1980) test. The Breusch-Pagan-Godfrey (Breusch and Pagan, 1979) and ARCH (Engle, 1982) tests are used to check for heteroscedasticity. These diagnostic tests ensure that the model's estimate is precise and unbiased.

3.3.4. Stability test

If the model has autoregressive properties, its stability is crucial for analyzing time series in general. This study uses the cumulative sum (CUSUM) (Brown et al., 1975) test and the cumulative sum of squares (CUSUMSQ) (Hansen, 1996) test for the ARDL model to verify its stability. By helping to identify structural fractures and instabilities in the model's estimated coefficients, these tests contribute to developing robust and dependable policies.

4. RESULTS AND DISCUSSION

The correlation matrix and descriptive statistics for the main variables examined in this study—CO_2 emissions, URB, DEF, GDP, and FD—are shown in Table 2.

A symmetrical distribution of the bulk of the variables may also be implied by the median values being relatively close to the means, and the mean values representing the middle points. Range quantifies variability by comparing the greatest and smallest values of the variables. GDP has the most significant variance on this scale, while URB has the least, and standard deviations further expand the measure of variability. The correlation matrix shows that as CO_2 emissions increase, so do EC, GDP, and URB. The correlation matrix demonstrates that when CO_2 emissions increase, so do EC, GDP, and URB. However, FD is found to deviate from the overall trend, exhibiting a high negative correlation with GDP and URB levels, and a slight inverse relationship with CO_2 emissions.

Table 2: Descriptive statistics and correlation

Variables	CO_2	URB	DEF	GDP	FD
Mean	−0.2179	3.5675	1.6536	7.0182	−1.3872
Median	−0.2230	3.5669	1.6538	7.1203	−1.5158
Maximum	0.0345	3.6386	1.7575	7.3906	−0.9917
Minimum	−0.4128	3.5019	1.5530	6.3965	−1.5992
SD	0.1235	0.0409	0.0635	0.3091	0.2241
Correlation Matrix	**CO_2**	**URB**	**DEF**	**GDP**	**FD**
CO_2	1				
URB	−0.2653	1			
DEF	−0.7102	0.5643	1		
GDP	0.6553	−0.7395	−0.9307	1	
FD	−0.2239	0.5438	0.7283	−0.7043	1

The Authors' own calculations of annual data for Pakistan from 2001 to 2023

4.1. Unit Root Results

It is crucial to ensure that none of the variables are integrated of order two, I(2), prior to doing the ARDL estimation, as this would render the bounds testing method invalid. Unit root tests were conducted using the Phillips-Perron (PP) and Augmented Dickey-Fuller (ADF) approaches to evaluate the order of integration. The results in Table 3 indicate that the CO_2 series is integrated of order one, I(1), under both the ADF and PP tests.

It is non-stationary at level but becomes stationary at first difference. In a similar vein, it is discovered that both urbanization (URB) and deforestation (DEF) are I(1) since they are non-stationary at level but become stationary at first difference. The same pattern applies to Financial Development (FD), which is also I(1) since it becomes stationary only after initial differencing. GDP, on the other hand, is integrated of order zero, or I(0), as it is shown to remain stationary at a level under both tests. These findings match the ARDL bounds testing framework requirements by confirming that none of the variables are I (2).

The use of the ARDL model to examine both short-term dynamics and long-term relationships between the variables is further supported by the combination of I (0) and I (1) variables. Lag length is a crucial factor to consider in the auto-regressive distributed lag model in order to provide reliable findings. The selection process for determining the number of lags uses the AIC, SC, and HQ, which are shown in Table 4. These criteria aid in choosing the appropriate lag order of the variables utilized for these reasons. The second lag (*) displays the lowest values of these criteria, as seen in Table 4. In compliance with the AIC's suggestion, the lag duration for this analysis is found to be two.

4.2. Lag Length Criteria

Table 5 below lists the F-statistics used in the cointegration test. Therefore, the crucial F-value was exceeded by the F-statistic computed and compared with the tabular value for α at the 10%, 5%, 2.5%, and 1% levels. For the data set utilized in the research, we thereby reject the null hypothesis, which suggests that there is no level of co-integration and that long-run linkages exist in the context of the model for the choice of variables at the 10%, 5%, 2.5%, and 1% significance levels.

Table 6 displays the results of the ARDL model, which captures the dynamics of the variables affecting CO_2 emissions over both the short and long terms. Urbanization (URB) has a statistically significant and positive impact in the short run, increasing CO_2 emissions by approximately 6.23 units while holding other factors constant. This suggests that rapid urban growth rapidly adds to environmental damage. Likewise, GDP has a strong positive relationship, with a unit gain in GDP translating into a 1.27-unit increase in CO_2 emissions.

Table 3: Unit root results

Variable	Augmented dickey-fuller		Decision	Phillips Perron (pp)		Decision
	I (0)	I (1)		I (0)	I (1)	
CO_2	−2.2729	−3.5787**		−2.0188	−2.7759***	
	(0.1836)	(0.0162)	I (1)	(0.2771)	(0.0787)	I (1)
URB	0.1529	−2.7252**		−0.9945	−2.6252**	
	(0.7201)	(0.0090)	I (1)	(0.2769)	(0.0080)	I (1)
DEf	−1.2517	−3.2745**	I (1)	−1.3407	−2.6810	I (1)
	(0.6326)	(0.0295)		(0.5917)	(0.0010)	
GDP	−3.3540**	---		−4.7579**	---	
	(0.0258)		I (0)	(0.0011)		I (0)
FD	0.2277	−2.1417**		0.2214	−2.3644*	
	(0.7420)	(0.0340)	I (1)	(0.7411)	(0.0207)	I (1)

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

Table 4: Criteria for lag length

Lag	AIC	SC	SQ
0	−15.50428	−15.20584	−15.43951
1	−22.96194	−20.8729	−22.50857
2	−27.80595*	−23.92630*	−26.96397*

Table 5: Bound test for integration

Test statistics	Value	K
F-Statistics	10.8688	4
Significance	**I (0)**	**I (1)**
10%	2.08	3
5%	2.39	3.38
2.5%	2.7	3.73
1%	3.06	4.15

Table 6: Short and long-run estimates of ARDL bound test

Dependent variable: CO_2 emissions (2, 2, 2, 2,1)				
Variable	Coefficient	Std. Error	t-statistic	Prob.
Short-term estimates				
D (URB)	6.2285	0.6240	9.9802**	0.0039
D (DEF)	−15.32227	1.4130	−10.8440**	0.0084
D (GDP)	1.2663	0.1715	7.3812**	0.0179
D (FD)	0.5451	0.1140	4.7776**	0.0411
CointEq (−1)	−6.8800	0.7429	−9.2603**	0.0116
Long-term estimates				
URB	0.5444	0.0666	8.1632*	0.0000
DEF	−0.0458	0.4446	−0.1030	0.9202
GDP	0.4787	0.0993	4.8187**	0.0113
FD	0.1347	0.0424	3.1738**	0.0113

*, ** shows 1% and 5% significance level

4.3. ARDL Bound Test

This suggests that economic growth is closely linked with short-run increases in pollution levels. The fact that financial development (FD) has a positive and substantial coefficient and raises emissions by 0.54 units suggests that financial activity may support industries with high emissions. Deforestation (DEF), on the other hand, has a startlingly negative short-run impact, indicating potential indirect or lag impacts on emissions. At −6.88, the error correction term (CointEq-1) is statistically significant and negative, indicating a rapid adjustment process following short-run deviations and confirming the existence of a stable long-term equilibrium relationship among the variables. Our study aligns with the findings of (Ahmed et al., 2015; He, 2015; Shahbaz and Lean, 2012; Stern, 2004).

With a coefficient of 0.54 in the long-run estimations, urbanization still has a considerable positive impact on CO_2 emissions, indicating the ongoing environmental strain that cities place on the environment. Economic and financial development over time contributes to environmental damage, as evidenced by the positive and statistically significant relationships between GDP and FD and CO_2 emissions. Deforestation may have a more immediate environmental impact than a long-run one, but it seems to have little long-term influence. The model's long-term stability and adjustment dynamics are validated by the large magnitude and significance of the error correction term, while urbanization and GDP are identified as the primary drivers of CO_2 emissions. Moreover, (Arshad et al., 2020; Arshad et al., 2020; Hassan et al., 2025; Raza and Shah, 2018) studies support our findings.

4.4. Diagnostic Test of the Model

With an R-squared value of 0.9731, the model created for Pakistan demonstrates excellent explanatory power, indicating that the chosen independent variables account for a significant amount of the variation in CO_2 emissions. Even after controlling several predictors, the adjusted R-squared value of 0.9483 demonstrates the model's robustness. Tests for serial correlation and heteroskedasticity were among the diagnostic procedures used to verify the regression model's main hypotheses. Both tests are above the traditional 5% significance level, with the Breusch-Pagan-Godfrey Heteroskedasticity Test yielding a probability of 0.1821 and the Breusch-Godfrey Serial Correlation LM Test returning a probability value of 0.1367. These findings support the validity and suitability of the ARDL specification for Pakistan by indicating that the model is not affected by autocorrelation or heteroskedasticity. The findings of these diagnostic tests are shown in Table 7, which generally attests to the model's statistical soundness and appropriateness for thorough policy analysis and interpretation.

4.5. Model Stability Test

The structural stability of the model was examined using the CUSUM and CUSUMSQ plots shown in Figures 1 and 2 of the current analysis. The total combined residual values for each variable are displayed in these figures, which include CUSUM, CUSUMSQ, and the 5% critical limit. The black ascending line represents the cumulative sum, and the 5% level of significance is indicated by the red lines, which are vertically dotted. The nature of the model parameters may change if the overall value at any given point exceeds certain crucial limiting thresholds.

Table 7: Diagnostic test

Test	F-statistics (Probability)
Breusch-Godfrey Serial Correlation LM test	0.1367
Breusch-Pagan-Godfrey Heteroskedasticity test	0.1821
R^2	0.9731
Adjusted R^2	0.9483

Figure 1: CUSUM at 5% significance level

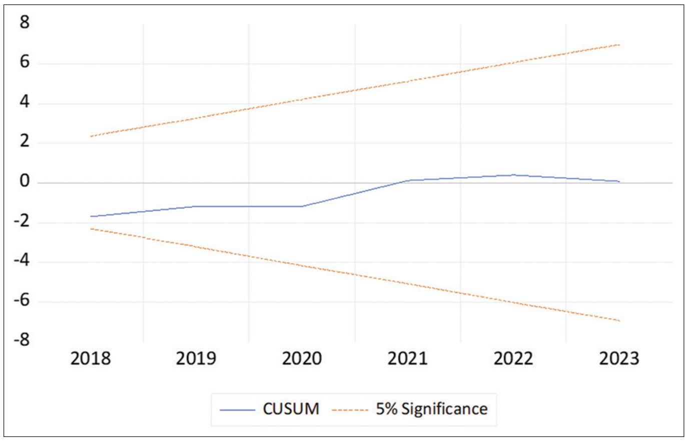
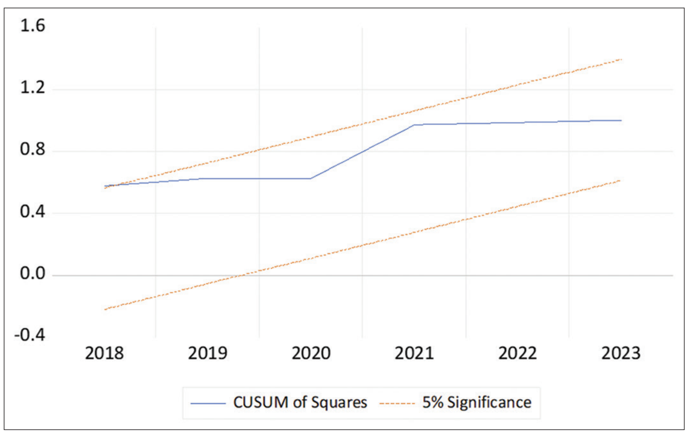


Figure 2: CUSUM of the square at a 5% significance level



The cumulative sum, however, remains below the critical lines, as can be seen from the two figures, indicating that the model parameters are stationary at the 5% significance level. This time measure is crucial for proving the stability and consistency of the model used in this investigation. Additionally, there were no signs of structural fractures or significant changes in the model's main parameters according to the CUSUM and CUSUMQ tests used in this investigation.

4.6. Policy and Governance Responses

With varying degrees of success, several new policies and programs have been introduced to mitigate deforestation, desertification, and water scarcity, and increased environmental awareness has been promoted as a key policy objective in Pakistan (Golo et al., 2024). Environmental issues need to be better integrated into key productive sectors, such as agriculture, forestry, and water management. Recent planning and policy documents have also acknowledged Pakistan's environmental preservation demands. The 7th 5-Y Plan document, which examines environmental achievements and deficiencies, emphasizes several afforestation plans and pollution control strategies. However, development planning rarely considers these environmental factors; the evaluation doesn't even mention the problems of water scarcity, desertification, or deforestation. The forestry industry's political, social, and economic issues, which have the most significant impact on environmental management, such as private company policies and operations, political and administrative institutions like the Forest Department, and resource ownership and access, are also frequently overlooked in attempts to achieve sustainable forestry. Only with significant democratization of the forestry industry and more extensive political and economic reforms could a planned transition to a more ecologically focused community-based resource management model succeed. Setting the scene for environmental governance involves not only international agreements but also local players. An intense focus on the effects of the "debt crisis" in the developing world has been prompted by worries about how it may affect other developing countries' financial programs and capacity to change current economic arrangements. These concerns may also have direct or indirect effects on the environment.

4.7. National Policies and Programs

The National Conservation Strategy and a ban on deforestation are two strategies the government has implemented to combat environmental degradation. Nowadays, forests serve as protection zones for ecotourism. The Ministry of Water and Power started a project to enhance range land management and reduce water waste in horticulture. There are initiatives in place to protect forests and wildlife in order to counteract desertification. To lessen urban floods in Katchi Abadis, the Ministry of Environment initiated a Storm Water Drainage Management project. The Parks and Horticulture Authority protect recreational woods, and conservation is aided by a 5% forest development tax on timber. In Sindh, a project to promote drip irrigation seeks to improve water efficiency. However, resource restrictions and isolated acts provide a challenge to these endeavors. For improved regional coordination, a comprehensive national strategy is necessary. Government effectiveness is hampered by obstacles such as a lack of political will, capacity problems, weakened institutions, a failure to apply standards, and an insufficient budget. Waheed et al. (2021) state that addressing environmental challenges requires the involvement of local communities and civic society. Community-based organizations (CBOs) promote cooperative forest management and increase public awareness of deforestation. The development project for Astola Island, Balochistan, to encourage sustainable island management, involved local communities. Increasing the ability of federal and provincial EPAs to monitor environmental regulations was one of the awareness-raising and social development projects. Land-use training assisted communities in the Kinhar River watershed area establish alternative energy sources and resource management infrastructure. Blanton et al., (2024) raised cleanliness awareness, and the Punjab Social Welfare Department started the Food Project Cleanup Campaign. A social team guaranteed adherence to environmental regulations. However, there is little data on these measures' benefits, so frequent evaluations are required. Since certain programs may have ulterior motives and impede the advantages to the community, transparency and accountability are essential. The results highlight how crucial national policy frameworks are for managing natural resources and tackling environmental issues. Risks can be reduced by wise land-use decisions, especially when it comes to flooding and other natural disasters.

4.8. Case Studies

Since its founding in 1947, Pakistan, a developing nation in South Asia, has had to deal with serious environmental issues. Through a variety of case studies, this study examines deforestation, desertification, and water scarcity as significant issues, revealing both effective remedies and enduring difficulties. With a chronological analysis from ancient to modern historical contexts, each instance provides distinct insights on environmental degradation throughout various regions of Pakistan. Despite the importance of archaeology, historical architecture, and urban planning, historical evidence is given precedence and is solely concerned with Pakistan's ecological environment (Aziz, 2023). Without addressing ethnographic insights or the societal knowledge of other nations, the study takes a national perspective. By discussing these various instances, the goal is to foster a critical and knowledgeable audience rather than just restating the project brief. This investigation seeks to improve knowledge of the intricacies within this broad area of the humanities and cognitive sciences in addition to providing a roadmap for researching different types of environmental deterioration.

4.9. Community Engagement and Sustainable Practices

Globally, environmental issues are a significant crisis. The lack of drinkable water, desertification, and deforestation are serious environmental problems. An effort is made to investigate how Pakistan's environment is affected by worldwide ecological trends. After examining Pakistan's current biodiversity, deforestation, desertification, and water scarcity, the management of forests and water in the context of global environmental challenges will be discussed. It encompasses not only forest management but also the management of vegetation of any type and the interrelationships between plants and other resources, particularly between the surrounding plants, soils, animals, and people. Because it frequently draws attention to the socioeconomic forces that propel environmental degradation, research on deforestation and desertification and its effects on the current global environment comes from various theoretical backgrounds, typically concentrating on political economy, geography, environmental history, and critical ecological economics. Nevertheless, much research ignores the contributions of biodiversity and local viewpoints to sustainability. Furthermore, local specificities and alternatives emphasize the need for more ethical, non-profit-driven relationships with ecosystems. At the same time, globalization and neoliberal policies in environmental management and development often focus on globalist issues. Building a different, more positive local perspective on development and environmental management that considers the needs and knowledge of the same disadvantaged populations would be insufficient, despite the strategic and destructive effects of livelihood strategies on the part of the poor. The effective conservation of biodiversity depends on the recognition of local knowledge, which would be maintained while promoting sustainable ecosystem management through the use of community resources and community governance. A better understanding of environmental issues, particularly deforestation, desertification, and water scarcity, will also be provided by presenting specific facts and analysis about Pakistan in light of these contexts (Ashiq and Hussain, 2023). This analysis should offer recommendations for the strategic possibility of eco-regional sustainable management that must benefit plants, animals, water, soils, and people, assisting local economies in their advancement. It does this by fusing internationally recognized scientific reasoning with local viewpoints. The conversation will focus on water resource management in addition to forests and deserts.

4.10. Potential remedies for deforestation include:

1. Cyclic agriculture is the solution to the issue of cattle grazing. This technique preserves soil fertility by rotating crops in a specific area
2. Efforts have been taken to prevent illicit logging, safeguard forested regions, amend trade agreements, and inform local communities in order to lessen the effects of forest and wood harvesting
3. Adopting a healthy lifestyle and lending support to groups that actively combat deforestation are crucial
4. All nations, governments, and private organizations must work to combat global deforestation, not only locally but also regarding resource imports, ensuring that all goods purchased are obtained responsibly.

5. CONCLUSION

This study aims to assess the impact of deforestation on greenhouse gas (GHG) emissions, considering the roles of financial development, urbanization, and GDP in Pakistan from 2001 to 2023. It also evaluates the effectiveness of environmental taxes in curbing emissions. The findings reveal that urbanization, GDP, and financial development significantly contribute to increased CO_2 emissions in the short and long run. On the other hand, deforestation demonstrates an adverse short-run effect with a minimal long-run impact. The model suggests a stable long-run equilibrium, with urbanization and GDP emerging as the primary factors driving emissions over time.

The loss of habitat and deforestation affects more than just a few plants and animals; these problems are directly related to human survival. Our already threatened planet is deteriorating more rapidly due to deforestation, which makes it increasingly difficult for humans, animals, and plants to survive. Globally, the need for additional land to sustain agricultural operations and population growth is causing wooded areas to disappear. In addition to upsetting ecosystems, this unrelenting loss puts vital ecological processes that support life on Earth in danger. Environmental education is essential to addressing this challenge. We can mitigate the harm caused by intentional human activity by increasing awareness, advocating for the preservation of natural forests, and supporting afforestation where necessary.

Given that trees are vital for water supply and that deforestation is accelerating desertification, these connections pose a severe threat to Pakistan's western regions. This critical situation underscored the need for comprehensive, immediate, and far-reaching solutions to address the pressing issues of water scarcity, desertification, and deforestation. These tactics must be addressed immediately, as their immediate effects could lead to long-term, irreversible consequences. Given the intricacy of ecological interconnections, the most effective strategies would take a multipronged approach that targets the various links of environmental concerns. Community-level initiatives can be implemented to lessen the detrimental effects of desertification and deforestation. Prioritizing community involvement in forest resource protection recognizes that growing population pressure on forest resources, which is directly linked to livelihood activities and inherited reliance on forests, is a significant cause of deforestation and water scarcity. Since it will be nearly impossible to replace these activities anytime soon, working with local communities to safeguard forests can at least stop illicit logging and lower the severity of water scarcity and desertification, which are closely related. The intricate long-term relationships between environmental issues in Pakistan necessitate an integrated approach that prioritizes the pursuit of technological innovation in sectors critical to environmental resilience and the comprehensive reform of national policies, as community involvement can only offer temporary respite.

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