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Toxic Trade Off – Pakistan's Pollution Crisis and the Paradox of Development

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ABSTRACT

This paper investigates in respect to environmental damage in Pakistan from 1972 to 2023 the interactions among industrialization, population increase, energy consumption, car registration. Using strict econometric approaches including unit root tests to evaluate stationarity, the Johansen Co-integration test to identify long- and short-run relationships, and the VAR lag order selection criterion for lag determination, the study analyzes these dynamics using ARDL (Autoregressive Distributed Lag) and ECM (Error , Correction Model). Using Log Likelihood, Akaike Information Criteria, and Schwarz Criteria helps one enhance model definition and lag interval options. The paper investigates the complex and bidirectional interactions among economic growth, energy consumption, and environmental damage, stressing that higher energy use and industrial activity greatly aggravate environmental damage including pollution and deforestation, so aggravating rising population and energy demands. Results expose a long-term favorable relationship between environmental damage and energy usage. The outcomes underline the need of deliberate interventions to balance environmental preservation with economic development by means of the encouragement of sustainable behaviors and cleaner energy sources. This thorough study emphasizes how urgently wise policy-making is needed to handle Pakistan's several environmental problems.

INTRODUCTION

Rising as a major issue for Pakistan, environmental damage seriously jeopardizes public health and sustainable development. Growing economically, Pakistan has seen fast industrialization, a rising population, rising energy consumption, and exponential automobile registration increase. Although these elements are sometimes praised for their contributions to economic

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development, they also significantly strain the environment and have negative effects including loss of biodiversity, deforestation, and air and water pollution.

In Pakistan, the junction of environmental damage, economic development, and energy use presents a difficult and multifarious conundrum. Among the major environmental challenges the nation faces are air and water pollution, deforestation, soil erosion, and a declining biodiversity. The great reliance of the energy industry on fossil fuels such coal, oil, and natural gas is a main cause of this environmental degradation. This dependence causes natural resources to be depleted, air pollution to be generated, and greenhouse gasses released. With a large share of its energy consumption coming from fossil fuels—more especially, natural gas and oil—Pakistan depends much on them. Using these fossil fuels for both transportation and electricity generation not only increases air pollution but also accelerates climate change by releasing methane (CH4) and carbon dioxide (CO2).

On the other hand, with industries, companies, and families reliant on it for different production and consumption activities, energy consumption is a pillar in propelling economic advancement. Population increase, urban development, and industrial advancement have driven ongoing demand for energy in Pakistan. Consequently, when the economy grows, the demand for energy increases to power sectors including manufacturing, agriculture, transportation, and services.

Therefore, for Pakistani legislators, juggling the need for environmental protection with economic development offers great difficulties. Policies meant to promote economic development—such as building infrastructure and industry—often give activities consuming a lot of energy top priority, therefore aggravating environmental damage. Nonetheless, initiatives to mitigate environmental effects—such as switching to renewable energy sources and applying energy efficiency policies—may call for initial outlays of funds and can thus slow down short-term economic expansion, and, tackling the complex nexus of energy consumption, economic growth, and environmental degradation demands collaborative action from the government, industry, civil society, and global partners. Among the vital steps are those toward a sustainable energy model, encouragement of energy efficiency, investment in renewable energy sources, and legislative harmonizing of economic growth with environmental protection. Securing environmental sustainability and ongoing prosperity for the country depends on these actions.

Addressing the intricate nexus between energy consumption, economic development, and environmental degradation requires a holistic approach that integrates social, economic, and environmental aspects of sustainability. By aligning energy policies with broader sustainable development objectives like poverty alleviation, social equity, and environmental conservation, Pakistan can facilitate a transition towards a more sustainable and resilient energy system. Solar, wind, hydro, and biomass resources among other renewable energy sources abound in the nation.

Investing in renewable energy infrastructure not only reduces reliance on fossil fuels but also stimulates economic growth, creates job opportunities, and fosters technological advancement. Nonetheless, obstacles such as high initial costs, regulatory hurdles, and inadequate infrastructure have impeded the widespread adoption of renewable energy technologies in Pakistan.

Problem Statement

Achieving sustainable economic development while managing energy production and consumption and avoiding environmental damage is absolutely vital in the global economy of today. A country is said to be economically rich when it successfully balances these components by means of coordinated policies. Pakistan battles with this balance, with issues including unsteady GDP growth, inflation, health concerns, a balance of payments imbalance, pervasive poverty, low living standards, and declining law and order, much as many rising economies do.

Further aggravating Pakistan's economic problems are environmental damage and an ongoing energy crisis. The government has not yet put in place thorough policies to handle these related problems, and present approaches are sometimes ill-considered and contradictory. This study intends to investigate the intricate interactions among industrial activity, population increase, energy consumption, and the growing number of registered vehicles—all of which have important consequences for Pakistan's environmental health and sustainability.

This paper will look at how industrial activity leads to environmental deterioration, the impact of population growth on ecological stress, the part energy consumption in environmental decline plays, and the consequences of more vehicles on environmental health. By means of an analysis of these linked elements, the study will offer a comprehensive knowledge of how environmental management and economic development interact in Pakistan. Developing sensible policies that strike a mix between environmental preservation and economic growth depends on addressing this research issue. The results will provide insightful analysis for sustainable development plans, therefore augmenting the larger conversation on environmental management and supporting long-term ecological stability in Pakistan and like nations of progress.

Research Question

The interrelationships of economic development, energy consumption, population increase, industrialization, automobile registration, and environmental damage in Pakistan are aimed to be investigated in this paper. It seeks to address multiple important questions:

1. In what ways does industrial activity worsen the surroundings?
2. In what sense does population increase aggravate environmental stress?
3. How important energy consumption is to the environmental deterioration?
4. How much of an influence rising car registrations have on environmental quality?

By tackling these problems, the research will assess the efficiency of present policies and offer understanding of the complicated connections among several elements. It will also suggest required legislative actions to handle current issues as well as those to come. This thorough study seeks to enhance the body of knowledge already in publication on sustainable economic development and environmental management by providing useful suggestions for Pakistan's strategy to strike a balance between environmental preservation and economic growth.

Objectives of the study

1. To investigate the impact of energy consumption, industrialization, population, vehicles registered and economic growth on environmental degradation in Pakistan.
2. To provide policy recommendation in the context of nexus between population, economic growth, industrialization, energy consumption, vehicles registered and environmental degradation in Pakistan.

Conceptual Framework

The complex interactions of industrialization, population increase, energy consumption, car registration, and their combined influence on environmental damage in Pakistan is investigated in this paper. A major issue is environmental damage marked by the degradation of natural resources and pollution growth. Indices of this deterioration include loss of biodiversity, soil erosion, contamination of air and water, and deforestation.

Industrialization is the spread of manufacturing activity inside a nation. Rising industrial activity often results in more pollution, more waste generation, and more resource depletion as well as other changes. Although industrialization can first aggravate environmental circumstances, over time the acceptance of greener technologies and more sustainable practices could help to lessen these negative effects.

The environment suffers more strain from population increase—that is, from more people living in Pakistan. Greater demand for resources such water, land, and energy resulting from an increasing population fuels environmental damage. Further pressuring environmental resources, the spread of metropolitan areas brought on by population rise can lead to deforestation and more garbage generation.

Energy consumption is the whole amount of energy consumed by a nation including both renewable sources and fossil fuels. Particularly from non-renewable sources like coal and oil, high degrees of energy use greatly add to greenhouse gas emissions and air pollution. Energy inefficiencies aggravate environmental resources even more, thus they become a major determinant of the total environmental impact.

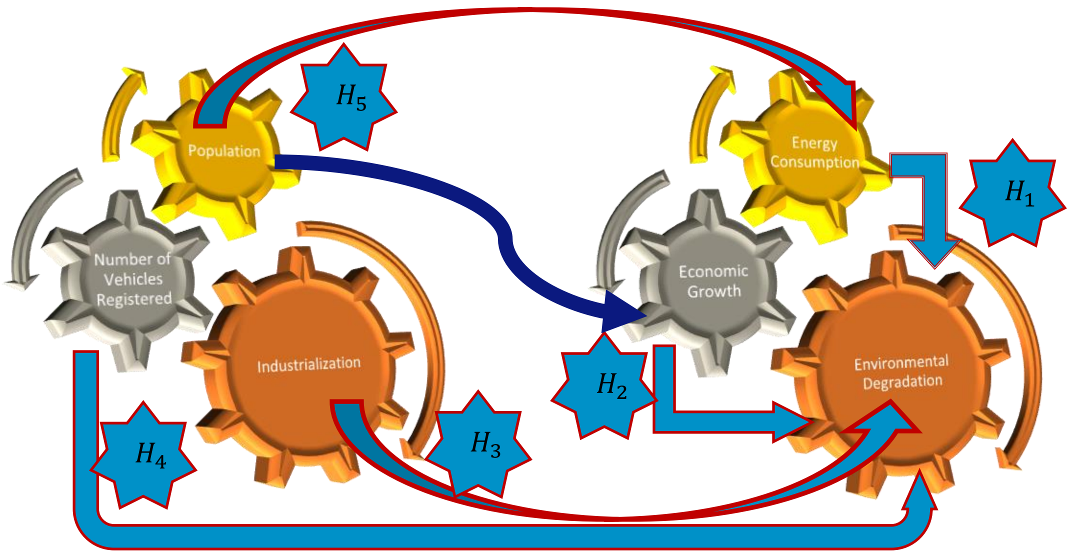
Another important consideration is the total count of registered vehicles—cars, lorries, and motorcycles among others. Higher emissions of pollutants including carbon monoxide, nitrogen oxides, and particulate matter follow from more automobiles. Apart from aggravating air pollution, this influences environmental quality and public health.

The interactions among several factors are complicated and linked. Rising energy consumption brought on by industrialization could aggravate environmental damage depending on the sustainability of the energy sources. On the other hand, fast industrialization sometimes draws people to metropolitan regions, therefore stressing environmental resources and raising population density. The demand for transportation rises with population, which drives more car registrations and more emissions.

Adopting an integrated strategy that balances industrial development, energy consumption, and population management is crucial if we are to properly solve environmental damage. Encouragement of greener technologies, renewable energy sources, and energy economy helps to lessen environmental effects. Furthermore helping to control the consequences of higher car registration is sustainable urban design and support of public transportation or electric vehicles.

This conceptual framework offers a disciplined knowledge of how industrialization, population increase, energy consumption, and car registration interact to affect environmental damage in Pakistan. By use of these linkages, the study seeks to provide insightful analysis on how best to create sustainable development and environmental management policies and strategies.

The basic outline of the research hypotheses – Conceptual Frame



The objective of this article is to investigate the intricate interaction among the drivers of economic growth—industrialization, population increase, energy consumption, and automobile expansion—that together affect environmental damage in Pakistan. We want to give a complex knowledge of how these elements contribute to environmental concerns by means of data patterns and policy consequences, therefore providing insights for legislators to balance economic growth with environmental sustainability.

LITERATURE REVIEW

Scholars have paid a lot of attention to the interactions among environmental policies, economic growth, and technological development. Still, there are somewhat large gaps, especially with relation to Pakistan's background. This review looks at important literature to show current knowledge and the areas where our work adds fresh insights. Ricci (2007) argues that while important for lowering pollution, environmental rules might cost companies extra money. These expenses could be production's limiting factor, so impeding economic progress. Albrizio et al. (2017) build on this point of view by implying that strict environmental rules could compel businesses to shift funds from profitable operations to pollution control initiatives, therefore slowing down economic development. Though perceptive, this viewpoint falls short in properly addressing Pakistan's particular economic and environmental issues.

On the other hand, Stern et al. (1996) highlight how bad environmental pollution is for human health, which would thus hinder economic development. Many research confirming the negative health consequences of pollution corroborate this link (Bouchoucha, 2021; WHO, 2017; Donohoe, 2003). These results show the need of tackling environmental problems but fall short of combining these issues with a thorough investigation of Pakistan's energy and economic consumption trends.

By suggesting that environmental problems might inspire technical innovation and economic development, Soytas and Sari (2009) offer a more complex picture. Environmental policies, they contend, can provide businesses incentives to embrace greener technologies and raise efficiency. This viewpoint implies that rather than only imposing restrictions, well-crafted environmental regulations could stimulate economic transformation. But this optimistic view of environmental policies has not been thoroughly investigated in the framework of Pakistan, therefore creating a gap that our study seeks to close.

Including Pakistan, research by Azam et al. (2016) looks at how carbon dioxide emissions relate to economic growth in South Asia. According to their research, carbon dioxide emissions can actually help to boost economic growth—against some predictions. This result offers a regional viewpoint but does not fully combine the intricate interactions between environmental damage particular to Pakistan, energy use, and economic development.

Rehman et al. (2021) and Acheampong et al. (2022) investigate, via several methodological techniques, the effect of carbon dioxide emissions on economic growth. While Acheampong et al. (2022) discover a similar negative correlation in the context of Ghana, Rehman et al. (2021) find a negative influence on economic growth. Their results, however, go counter to those of Azam et al. (2016), who saw improvements in South Asia. These conflicting findings highlight the need of a more complex study particular to Pakistan.

Research like those by Dell et al. (2009) and the Swiss Re Institute (SRI, 2021) adds still another level of complication. While SRI (2021) anticipates significant worldwide economic repercussions from climate change, Dell et al. (2009) estimate that national GDP per capita drops by about 8.5% for each degree Celsius increase in temperature. These forecasts underline the great financial concerns connected to increasing temperatures and support the need of solving environmental problems. These studies, however, concentrate more on larger regional and worldwide settings and lack particular understanding of Pakistan's particular environmental and economic problems.

Furthermore quite important in the literature are methodological developments. A strong solution for endogeneity problems in econometric analysis is provided by the dynamic system-generalized method of moments (Blundell & Bond, 1998). Using such approaches in Pakistan's situation could help one to have a more realistic knowledge of the interactions among environmental policies, economic development, and technological innovation.

In conclusion, there is still a clear void in thorough study targeted on Pakistan even if current studies provide insightful analysis of the interactions among environmental policies, economic development, and technological improvement. By means of a multidimensional analysis of how energy consumption, economic development, industrialization, population increase, and automobile registration affect environmental damage in Pakistan, our study seeks to close this disparity. This study will provide fresh ideas on juggling economic progress with environmental sustainability in Pakistan by combining these elements with sophisticated econometric approaches.

Research Gap

Though much study has been done on environmental damage, little is known about the particular interaction of economic development, energy consumption, industrialization, population increase, automobile registration in Pakistan. This study fills in important voids by means of a multidimensional analysis combining these factors in an innovative manner not thus methodically done.

Research already conducted in Pakistan has mostly concentrated on single elements of environmental damage without a thorough framework tying several factors at once. Studies such as those by [Ali et al. (2022) look at how industrialization affects pollution; meanwhile, [Khan et al. (2023) evaluate the part energy consumption plays in environmental degradation. On environmental damage, no study has, however, simultaneously taken into account the linked effects of economic expansion, energy consumption, industrialization, population increase, and car registration. This work is special in its method since it combines several elements to give a whole picture of their combined influence.

Previous studies have sometimes missed some factors like population increase and registered car count. Studies like [Rashid and Khan (2021)] have not sufficiently included how population dynamics and vehicle proliferation contribute to environmental stress, even when the impact of industrialization and energy consumption on environmental deterioration has been recorded. Including these underappreciated factors helps our study close a significant knowledge gap on the whole effects on environmental degradation.

Many of the current studies use cross-sectional data, which provides scant understanding of long-term trends. For instance, [Iqbal et al. (2021) have looked at the short-term effects of industrialization but have not followed how long-term interaction of energy consumption, economic growth, and other factors influences environmental deterioration over time. This work will make use of longitudinal data to offer a more realistic picture of how these elements change and interact over lengthy times.

Focusing on one or two variables at a time, the current literature sometimes depends on single-dimensional methods. For example, [Zafar et al. (2022) look at energy consumption effects in isolation, without including the consequences of other elements as industrialization and automobile registration. This study is unique and required for a more complex knowledge of their combined influence on environmental deterioration since it uses a multidimensional approach and considers many variables concurrently.

Studies already in publication have usually failed to offer practical policy suggestions grounded on combined evaluations of these factors. For instance, [Hussain and Ahmed (2022) cover environmental policies in a general sense but do not provide particular plans that handle the linked effects of industrial activity, energy consumption, and economic growth. By providing focused policy insights and suggestions based on the cumulative effects of all taken into account variables, this study seeks to close this gap.

By providing a thorough and integrated examination of the effects of economic growth, energy consumption, industrialization, population increase, and car registration on environmental degradation in Pakistan, this study essentially fills in important voids in the present literature. This work will offer fresh understanding of the intricate interactions among these factors by including neglected determinants and applying a multidimensional analytical model. Moreover, the study will provide insightful policy suggestions that will help Pakistan to have a more complex knowledge of how to reconcile environmental sustainability with economic development. Under the framework of a developing nation, this strategy seems to greatly forward the conversation on environmental management and sustainable development.

METHODOLOGY

Theoretical Frame

Analyzing "Environmental Degradation in Pakistan: Impacts of Industrialization, Population Growth, Energy Consumption, and Vehicle Registration" uses a theoretical framework combining numerous important ideas to offer a whole picture of the interactions among these factors. The Environmental Kuznets Curve (EKC) proposes that although first economic development results in more environmental damage, greater wealth levels can finally help to promote improved environmental rules and technology. Neoclassical economic theory holds that, given suitable rules, market systems may effectively solve environmental problems.

According to the Theory of technical Innovation, environmental problems can inspire technical development, therefore helping to promote economic progress. The Population-Environment Nexus Theory emphasizes how increasing resource use by population growth increases environmental stress. The Tragedy of the Commons idea shows how unbridled usage of common resources could cause environmental degradation. The Energy-Economy-Environment Nexus combines environmental health and economic activity's effects on energy usage.

Finally, Endogenous Growth Theory holds that environmental sustainability can be influenced and economic development driven by internal elements including human capital and technical advancement. Combining these theories, the framework seeks to investigate the intricate interactions among economic development, energy use, industrialization, population growth, and vehicle registration in Pakistan, so identifying sensible policies that strike a balance between environmental preservation and economic growth.

Data and Variables

This study looks at the linked factors using statistics covering 1972 to 2023. The study analyzes the long-term trends and interactions among several elements holistically using many sources. From a number of reliable sources—including national statistical databases, official papers, and scholarly research—data on economic growth, industrialization, energy consumption, population dynamics, and automobile registration have been gathered. This long temporal coverage enables a comprehensive study of how these factors have changed and interacted over more than five decades, therefore offering insightful analysis of their influence on environmental damage in Pakistan.

Gross Domestic Product (GDP)	GDP indicates a nation's economic situation and gauges its overall economic output. Services, manufacturing, and agriculture all help to determine Pakistan's GDP. Important obstacles include political unrest, energy shortages, and a sizable unofficial economy. Notwithstanding these challenges, strategic projects like the China-Pakistan Economic Corridor (CPEC) and continuous reforms have promise for expansion.
Energy Consumption (EC)	Development of Pakistan depends on energy usage, which influences services, manufacturing, and agriculture. With issues on energy security and efficiency, the energy mix consists of fossil fuels, hydropower, and renewable sources. Problems such load shedding and circular debt complicate the industry and call for thorough changes including investments in renewable energy.
Environmental Degradation (ED)	Among Pakistan's major environmental problems are inappropriate waste management, air pollution, water scarcity, and deforestation. These issues effect public health, ecosystems, and climate resilience. Dealing with these issues calls for integrated water management, more afforestation, better waste control, and more environmental rules.
Population (POP)	Pakistan's roughly 250 million population reflects both possibilities and problems in terms of demographic patterns. If supported by enough healthcare, education, and employment possibilities, a young population could propel economic development. Harnessing this demographic potential depends critically on efficient family planning and resource management.
Industrialization (IN)	In Pakistan, industrialization covers services, manufacturing, and textiles as well as other sectors, so promoting economic development. Notwithstanding advancements, problems including infrastructure

	constraints and energy shortages impede sector expansion. By use of infrastructure and special economic zones, the China-Pakistan Economic Corridor (CPEC) seeks to increase industrial growth.
Number of Vehicles (VN)	Pakistan's rising car count indicates both economic development and urbanization. Although they increase mobility, automobiles cause traffic congestion, pollution, and infrastructure strain. To solve these problems policies supporting public transportation, greener fuels, and pollution control are required.

Model Specification

The present study is special in that, applying a multidimensional approach, Pakistan has not done any thorough and methodically based investigation on the specified factors. For the first time, this study will offer Pakistan an integrated research concurrently addressing environmental damage, energy consumption, and economic growth. Some of the new factors—population, industrialization, and car registration count—that have been overlooked in past times will be incorporated. This will be the first thorough investigation on the interaction among Pakistan's environmental damage, energy use, and economic development.The model of the study investigates on Environmental Degradation (ED) the effects of Energy Consumption (EC), GDP, Value Index of Industrialization (IN), number of Registered Vehicles (NV), and Population (POP).

$$\boldsymbol{ED = F\ (EC, GDP, IN, NV, PoP)}$$

The study underlines Pakistan's environmental problems and main causes of deterioration. Strong dependence on fossil fuels fuels energy consumption, hence aggravating environmental damage. As vehicle count and population increase, urban pollution gets worse. Oddly, industrialization has a negative relationship to degradation—probably because of better technology. Reduced degradation also links with GDP growth, implying a complicated equilibrium between environmental health and economic progress. Policymakers are urged to give renewable energy sources top priority in order to sustainably satisfy the nation's energy demand.

Promoting environmentally friendly technologies across sectors and stressing sustainable mobility options can help to reduce environmental damage even while they boost economic development. The model of the research investigates on Environmental Degradation (ED) the effects of Energy Consumption (EC), Gross Domestic Product (GDP), Value Index of Industrialization (IN), number of Registered Vehicles (NV), and Population (POP).

$$ED_t = \alpha + \beta_i EC_t + \gamma_i GDP_t + \delta_i IN_t + \lambda_i NV_t + \chi_i POP_t + \varepsilon_t$$

Whereas ε_t is the error term and α , β_i , δ_i , λ_i , χ_i , σ_i are the respective coefficients.

Empirical Analysis

Dealing with stationarity in time series data is a great difficulty that emphasizes the need of a thorough variable evaluation before applying the ARDL model. In applied econometrics, conventional approaches may rely on the presumption of normality—that is, on the idea that the mean and variance remain constant throughout time. But defining them as unit root variables, economic factors often show changes in their mean and variance. Particularly in non-stationary data, the traditional techniques—including ordinary least squares (OLS)—are prone to provide biassed and erratic estimations. For this reason, in this study we evaluate the stationarity of our variables using strict unit root tests. Furthermore assuming bilaterla causality, this study investigates the casualty among the key dependent variables: GDP〗 _t, EC〗 _t, ED〗 _t, so reflecting the variables under analysis.

The study estimates three autoregressive models for every dependent variable in this regard. Two models—one incorporating lagged values of both variables and the other only lagged values of one variable—have their residual sum of squares (RSS) compared to get the test statistic. Assumed to be the null hypothesis, this comparison follows an F-distribution. In our model, expecting divergent results and causality, we can either utilize the ARDL model (should there be no long term association or cointegration between the variables in our first model) or ECM model (should the variables be cointegrated) or VAR in case bilaterla causality exists.`

At last, we will utilize the cointegration test—to examine the long run relationship—to decide which model—among ARDL or ECM—should be employed for the investigation. In non-stationary time series data especially, it is relevant. Often showing trends or random walks, non-stationary time series data contain statistical characteristics that evolve across time. In financial and economic applications, one often finds variables that are individually non-stationary yet may have a stable long-term connection when taken together. One can find and replicate such correlations by means of co-integration. The main concept behind cointegration is that a linear combination of even if individual time series might not be stationary. A set of variables is formally cointegrated if a linear combination of them produces a stationary time series. This suggests that although every variable might have a random walk or a trending behavior on its own, some mix of them is mean-reverting or stationary. The Johansen test is a widely used statistical test with this aim in order to identify cointegration in a collection of time series data. Even if these variables are individually non-stationary, cointegration suggests a long-run interaction between them. Analyzing the dynamics of economic variables that can have a shared stochastic tendency calls especially for this approach.

The ARDL model offers a versatile structure for simulating the long-run interaction between variables with various order of integration. The ECM captures short-term dynamics and the correcting mechanism, therefore complementing the ARDL. The presence of co-integration in the ARDL framework is then sought for using the Bound Test.

Augmented Dickey-Fuller (ADF)

Whether a time series dataset has a unit root—that is, if the series exhibits a stochastic trend and is non-stationary—is found by the Augmented Dickey-Fuller (ADF) test. The ADF test addresses serial correlation by adding lagged values of the variable, hence expanding the original Dickey-Fuller test.

Before applying the ARDL model, it is imperative to address stationarity in time series data since many economic variables cannot be assumed constant mean and variance by conventional econometric techniques. With techniques like ordinary least squares (OLS), non-stationary data can produce biassed and incorrect conclusions. The stationarity of our variables is assessed in this paper via the ADF test. While the alternative hypothesis holds that the time series lacks a unit root (stationary), the null hypothesis of the ADF test is that it has a unit root (non-stationary).

Composite Table of Unit roots test results of all variables at LEVEL and 1st Difference

Variables	I(0)	I(1)
EC	0.0228	0.0031
ED	0.0145	-
GDP	0.9040	0.0047
NV	0.8252	0.0000
POP	0.0004	-
IN	0.8939	0.0354

The data results of the unit root lead one to conclude that every variable in our model is not stationary at level. Consequently, the ARDL approach of analysis will be the quantitative one employed to estimate the link among energy use, economic development and environmental damage. Still, we have to check for bidirectional causality and cointegration before implementing ARDL or ECM. Should Granger causality exist, we xill apply VAR oitherwise the analysis will stick tp either ARDL or ECM.Granger.

Granger Causality Test

The Granger causality test is a key method in econometrics used to determine if one time series can predict another. Developed by Clive Granger in 1969, it is crucial for examining causal relationships between economic variables over time. In this study, the test is applied to evaluate the causal relationship between the primary dependent variables, EC_t, ED_t,. To determine causality, the study involves estimating two autoregressive models for each of these dependent variables.

In econometrics, the Granger causality test is a fundamental technique used to find whether one time series can forecast another. Designed by Clive Granger in 1969, it is absolutely essential for analyzing over time causal links between economic variables. This work uses the test to assess the causal link between the main dependent variables, EC_t, ED_t,. Estimating two autoregressive models for every one of these dependent variables helps one ascertain causality.

$$ED_t = \sum_{i=1}^{\tau} \beta_i \boldsymbol{ED_{t-i}} + \sum_{i=1}^{\tau} \gamma_i \boldsymbol{EC_{t-j}} + \varepsilon_t$$

$$EC_t = \sum_{i=1}^{\tau} \delta_i \boldsymbol{EC_{t-i}} + \sum_{i=1}^{\tau} \lambda_i \boldsymbol{ED_{t-j}} + v_t$$

$$ED_t = \sum_{i=1}^{\tau} \beta_i \boldsymbol{ED_{t-i}} + \sum_{i=1}^{\tau} \gamma_i \boldsymbol{GDP_{t-j}} + \varepsilon_t$$

$$GDP_t = \sum_{i=1}^{\tau} \delta_i \boldsymbol{GDP_{t-i}} + \sum_{i=1}^{\tau} \lambda_i \boldsymbol{ED_{t-j}} + v_t$$

The null hypothesis of the Granger causality test holds that previous values of one variable do not affect the current values of another variable (or vice versa), therefore rendering all coefficients (δ_i or λ_i or β_i or γ_i) zero. The residual sum of squares (RSS) from two models—one including lagged values of both variables and one including lagged values of just one variable—are compared to assess this. Under the null hypothesis, we evaluate this comparison using an F-distribution. The null hypothesis is disproved if the computed F-statistic is higher than the critical value derived from the F-distribution at a 5% significance level, therefore suggesting a causal link whereby past values of one variable help forecast the other.

Null Hypothesis:	F-Statistic	Prob.
ED does not Granger Cause GDP	12.26736	0.1174
GDP does not Granger Cause ED	0.54998	0.5815

The Granger causality test's findings on the relationship between environmental degradation (ED) and Gross Domestic Product (GDP) expose insufficient data to refute the premise that ED does not Granger-cause GDP. Similarly, the study does not support disprobing the theory that GDP does not Granger-cause environmental damage. Consequently, it seems that neither measure effects the other causally since GDP and ED in both directions show no causal link. Still more

Null Hypothesis:	F-Statistic	Prob.
ED does not Granger Cause EC	14.3889	2.0965
EC does not Granger Cause ED	1.93492	0.1584

The Granger causality test findings for the interaction between environmental degradation (ED) and energy consumption (EC) indicate insufficient data to refute the theory that EC does not Granger-cause ED. In a same vein, the study offers no evidence to disprove the theory that ED does not Granger-cause EC. This implies, then, that ED and EC have no causal link, so neither variable influences the other.

Cointegration test

Several variables in the model utilized show stationarity at the level and others show stationarity at the first difference. Under this situation, we have two possible methods: the Error Correction Model (ECM) should cointegration exist among the variables; else, the Autoregressive Distributed Lag (ARDL) model. Thus, especially in non-stationary time series data, it is imperative to do a cointegration test to ascertain whether a long-term relationship exists among the variables in our first model. Often displaying patterns or random walks, non-stationary time series data are defined by changing statistical characteristics across time. Combining individual non-stationary variables may show a consistent long-term link in financial and economic settings.

The fundamental idea of cointegration implies that a linear combination of several time series could produce a stationary time series even if individual time series might not be stationar. A set of variables is said to be cointegrated simply if a linear combination of them produces a stationary time series. This suggests that some combination of the variables shows mean-reverting or stationary behavior whereas each one may follow a random walk or exhibit individual trend.

This work will use a cointegration test to evaluate the effect of shocks on the changing interactions among variables over time and to understand these interactions. The Johansen test is therefore a rather popular statistical tool for identifying cointegration in a collection of time series data.

Johansen Cointegration test

Though every variable demonstrates non-stationary behavior, the Johansen cointegration model is a statistical method used to investigate long-term interactions between several time series variables. Analyzing economic variables that can show a shared stochastic trend benefits greatly from it. Applied extensively in econometrics and time series analysis, this approach clarifies long-term links between variables and their short-term fluctuations.

Determining the trend and intercept assumptions

Finding the suitable lag intervals and knowing the presumptions for the test, which evaluates long-term relationships, is crucial before applying the Johansen cointegration model. This entails delineating five main presumptions: no deterministic patterns in the data, the existence of linear deterministic trends, and the allowance for quadratic deterministic trends.

Selected (0.05 leveI*)Number of Cointegrating Relations by Model

Data Trend:	None	None	Linear	Linear	Quadratic
Test Type	No Intercept	Intercept	Intercept	Intercept	Intercept
Trace	2	3	3	2	2
Max-Eig	2	2	2	2	2
Critical values based on Mackinnon-Haug-Michelis (1999)					

Information Criteria by Rank and Model					
Data Trend:	None	None	Linear	Linear	Quadratic
Rank or	No Intercept	Intercept	Intercept	Intercept	Intercept

Using three criteria—Log Likelihood, Akaike Information Criteria (AIC), and Schwarz Criteria (SBC)—the study finds the suitable assumptions and lag intervals. The best lag length and assumptions for the Johansen cointegration model are chosen by means of these criteria evaluating several ranks (rows) and models (columns). Using two criteria - Akaike information criteria by rank & model and model and schwarz criteria by rank & model, the stated deterministic model condensed all the sets of information for our model (Appendix I). Rows are showing lag intervals; columns are standing for assumption. While schwarz criteria by rank and model recommend the first assumption describing the lag interval to be at 1st lag as well, based on Akaike information criteria by rank the 5th assumption is to be selected with

2nd lag interval (Quadratic deterministic model). No deterministic trend in the data.

Johansen trace test or the maximum eigenvalue

Using the Akaike information criterion by rank - we have selected the fifth assumption and second lag to investigate the presence of cointegration among the variables and to check whether our model variables are cointegrated and long term association or not, based on these outcomes. Johansen trace test or maximum eigenvalue test

Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob.
None *	0.969766	303.7573	107.3466	0.0000
At most 1 *	0.807591	156.8086	79.34145	0.0000
At most 2 :	0.567638	87.58702	55.24578	0.0000
At most 3 *	0.435826	52.37034	35.01090	0.0003
At most 4 *	0.381816	28.32989	18.39771	0.0015
At most 5 *	0.175973	8.129205	3.841465	0.0044

Unrestricted Cointegration Rank Test (Maximum Eigenvalue)

Hypothesized No. of CE(s)	Eigenvalue	Max-Eigen Statistic	0.05 Critical Value	Prob. "*
None *	0.969766	146.9487	43.41977	0.0000
At most 1*	0.807591	69.22154	37.16359	0.0000
At most 2*	0.567638	35.21668	30.81507	0.0136
At most 3	0.435826	24.04046	24.25202	0.0533
At most 4*	0.381816	20.20068	17.14769	0.0175
At most 5*	0.175973	8.129205	3.841465	0.0044

The test finds whether variables have a long-term relationship (cointegration) using crucial values. If the probability value is 5% or less or if the trace statistics exceed the critical values for the presumed number of cointegral equations (CEs), we reject the null hypothesis of no cointegration. We accept the null hypothesis if the probability value exceeds 5% or the trace statistics are below the critical values.

The trace test as well as the maximum Eigenvalue test. Both tests let us discover that the null hypothesis of no cointegration is refuted. For most proposed CEs, the probability values are less than 5%; yet, the trace statistics surpass the crucial values. Consequently, we find that among the variables our third model shows a long-term correlation.

ARDL, Error correction Model and Bound test

Analyzing long-term interactions among variables with varying degrees of integration is made flexible by the ARDL approach. It addresses stationarity at several degrees and performs effectively with both integrated and non-integrated variables. The Error Correction Model (ECM) tackles short-term dynamics and corrections alongside the ARDL model. Cointegration is then checked inside the ARDL framework using the Bound Test. In econometrics, these techniques are routinely employed to investigate intricate economic time series data.

Examined in the long run between Environmental Degradation (ED) and many variables: Energy Consumption (EC), Gross Domestic Product (GDP), Value Index of Industrialization (IN), Number of Registered Vehicles (NV), and Population (POP) the ARDL model is used.

$$\boldsymbol{ED_t} = \alpha + \sum_{i=1}^{\tau} \beta_i \boldsymbol{EC_{t-i}} + + \sum_{i=1}^{\tau} \delta_i \boldsymbol{GDP_{t-i}} + \sum_{i=1}^{\tau} \lambda_i \boldsymbol{IN_{t-i}} + \sum_{i=1}^{\tau} \lambda_i \boldsymbol{NV_{t-i}} + \sum_{i=1}^{\tau} \lambda_i \boldsymbol{POP_{t-i}} + + \varepsilon_t$$

Derived from the ARDL model, the ECM captures the speed of adaptation in response to departures from the long-run equilibrium as well as the short-term dynamics. The ARDL model gains an error correcting term:

$$\Delta \boldsymbol{ED_t} = \alpha + \sum_{i=1}^{\tau} \beta_i \Delta \boldsymbol{EC_{t-i}} + \sum_{i=1}^{\tau} \gamma_i \Delta \boldsymbol{GDP_{t-i}} + \sum_{i=1}^{\tau} \delta_i \Delta \boldsymbol{IN_{t-i}} + \sum_{i=1}^{\tau} \lambda_i \Delta \boldsymbol{NV_{t-i}} + \sum_{i=1}^{\tau} \lambda_i \Delta \boldsymbol{POP_{t-i}} + \varepsilon_t$$

The rectification of errors term shows the speed with which a system gets back to long-term equilibrium following deviations. The Bound Test is used officially in the ARDL model to estimate two regressions: one with levels and another with initial differences, hence assessing cointegration. Subsequently, an F-test contrasts the alternative hypothesis of cointegration with the null hypothesis of no cointegration. The F-statistic exceeding the crucial values indicates probably cointegration is present.

Autoregressive Distributed Lag (ARDL):

Especially when dealing with a mixture of integrated orders in the data, the ARDL framework is a flexible tool for looking at the long-standing correlations among several time series variables. These models provide a combination of integrated and non-integrated series by include lagged levels as well as first differences of variables. Using ARDL models is appropriate given the different degrees of stationarity among our variables in investigating their interactions. But before diving into ARDL analysis, we must first determine the suitable lag length for our investigation and run the bound test, which closely examines the existence of cointegration—a sign of a stable long-term link among the variables.

VAR lag order selection criterion:

Accurate outcomes in a Vector Autoregression (VAR) model depend on proper lag order choice. Different criteria support this decision: the Akaike Information Criteria (AIC) balances fit and complexity by penalizing extra parameters; the Bayesian Information Criteria (BIC) applies a stricter penalty to prevent overfitting; and the Hannan-Quinn Information Criteria (HQIC) offers a different penalty balancing. By use of a comparison between the residual covariance matrix's determinant and the number of observations, the Final Prediction Error (FPE) evaluates model performance. While Cross-Validation (CV) chooses the lag order that reduces prediction errors on a testing set, Sequential Testing (ST) estimates models with growing delays and employs hypothesis tests to identify the ideal lag duration. These techniques assist to guarantee the accuracy and efficiency of the VAR model.

It is advisable to consider several variables while deciding the lag order since it guarantees a strong analysis. Choosing a lag order consistent across several criteria improves the validity and dependability of the study (Appendix II). Considering several criteria and adopting a lag order consistent across several criteria is usually a good habit when deciding the lag order.

Lag	LogL	LR	FPE	AIC	SC	HQ
0	-365.7007	NA	4395005.	18.13174	18.38251	18.22306
1	-363.9633	2.881518	4245074.	18.09577	18.38833	18.20230
2	-359.4840	7.210551	3588484.	17.92605	18.26040	18.04780
3	-356.8184	4.160971*	3315717. *	17.84480*	18.22095*	17.98177*
4	-356.6685	0.226716	3465690.	17.88627	18.30421	18.03846

The outcomes of our third model, in which Environmental Degradation (ED) is regressed on Energy consumption (EC), Gross Domestic Product (GDP), Value Index of Industrialization (IN), number of Registered Vehicles (NV), and Population (POP), show that all the criterion (FPE, AIC, SC and HQ and LR) suggests the third lag order to be used for the lagged levels to capture the long term relationship. Keeping the trend specification unchanged, we will thus computed the ARDL at 3rd lag criterion for both dependant variable and regressors.

ARDL

While Industrialization (IN) and Gross Domestic Product (GDP) help in mitigate the Environmental Degradation (ED), the ARDL model (selected ARDL 4, 4, 4, 4, 2, 4) results show that the Energy Consumption (EC), number of Registered Vehicles (NV) and Population (POP) blows out (further deteriorate) the Environmental Degradation (ED). With 99 percent ascribed to the independent variables: energy consumption, foreign direct investment (FDI), gross capital formation, and public debt, the ARDL results concerning our first model show a significant explanation of the variance in the Gross Domestic Product (GDP).

Though statistically little, the effect of energy use on GDP shows a remarkable correlation of 12.45. This finding emphasizes the important link between energy consumption and economic development in Pakistan in keeping with the general consensus stressing its vital function in developing countries. Though with an eye on environmental sustainability, dependable energy supplies fuel industrialization, infrastructure development, and technological innovations.

A coefficient of 0.86 and statistical relevance show how clearly public debt affects GDP. This emphasizes how dependent on debt-driven economic development Pakistan is. Nonetheless, it's important to recognize the complex character of the link between public debt and economic growth, which calls for sensible fiscal policies and structural changes to reduce related risks.

A coefficient of 0.153 and statistical insignificance suggest a small effect of gross fixed capital creation (GFCF) on GDP. Still, GFCF is essential for promoting economic development since infrastructure and technology increase production capacity and GDP expansion. But macroeconomic stability, infrastructure quality, and investment efficiency will determine how effective GFCF is.

With a coefficient signaling a decrease in GDP per unit increase in FDI, foreign direct investment (FDI) shows a significant and statistically negative effect on GDP. FDI's negative consequences in Pakistan call attention even if its generally expected benefits. Concentrated gains, resource drainage, and social inequalities highlight the need of strategic FDI management to maximize its possible advantages while lowering related risks.

ARDL long Run form and Bound Test

As was already said, the cointegration analysis reveals in our model a long-term link among the variables. Conditional error correction regression is applied to validate this, then compared with the Bound Test, a widely used method for cointegration evaluation within the ARDL modeling framework. Two ARDL models are approximated in the Bound Test: one without constraints on lagged level coefficients set to zero and one with. We compute the F-statistic to find whether the unconstrained model fits notably better than the limited model. We reject the null hypothesis of no cointegration and imply a long-term link if the F-statistic above the critical value.

Significant findings are obtained using the F-Bound test and t-Bound test applied with an unrestricted constant and 'No Trend Model'. We reject the null hypothesis of no cointegration by means of the F-statistic value of 12.6 exceeding the I(0) bound value of 2.45 and the t-statistic value of 1.27 exceeding the I(0) bound value of -2.57. This attests to the existence of a long-term correlation among the variables.Another set of Bound Test results shows conflicting results: the absolute value of the F-bound statistic (4.29) exceeds the I(0) bound value of 2.26, so supporting cointegration; the absolute value of the t-bound statistic (-3.3) falls below the I(0) bound value of -2.57, so suggesting no cointegration (Appendix IV). Confirming ARDL-based cointegration in our third model becomes difficult with this contradicting result. This calls for more research.

ARDL Error correction Regression

Analyzing correlations between variables depends on an error correction model (ECM), particularly in cases of non-stationary time series data and cointegration. Although individual variables might not be stationary, their linear combination can be stable over long times according to co-integration. ECMs account for short-term fluctuations and preserve long-term relationships unlike conventional techniques that alter non-stationary data to reach stationarity. An ECM's main component is the error correction term (ECT), which gauges the speed with which a variable recovers to its long-term equilibrium following brief disturbances. Capturing the process of restoring long-term equilibrium, the ECT reflects the difference between actual and expected values depending on the cointegrating connection. This work develops an initial model integrating these ideas using ECM technique.

$$\begin{aligned}\Delta ED_t = {} & \alpha(ED_{t-1} - EC_{t-1}) + \beta(ED_{t-1} - GDP_{t-1}) + \gamma(ED_{t-1} - IN_{t-1}) \\ & + \sigma(ED_{t-1} - NV_{t-1}) + \eta(ED_{t-1} - POP_{t-1}) + \lambda_1 \Delta ED_{t-1} + \lambda_2 \Delta EC_{t-1} \\ & + \lambda_3 \Delta PD_{t-1} + \lambda_4 \Delta FDI_{t-1} + \lambda_5 \Delta GFCF_{t-1} + \varepsilon_t\end{aligned}$$

Where Δ denotes the lag values $(t-1)$ of every variable, α indicates the speed of adjustment—that is, the coefficient of the error correction term and λ_i are coefficients for the lagged variations. With the varying degree of each variable, ARDL and ECM analysis presents practically the same tale (Appendix V).

The results show that the lagged values (1st difference) of Environmental Degradation (ED) are significantly influenced by the lagged values (1st difference) of Energy Consumption (EC), Gross Domestic Product (GDP), Value Index of Industrialization (IN), number of Registered Vehicles (NV), and Population (POP). These outcomes reflect those found using the Autoregressive Distributed Lag (ARDL) method applied to the same model. The results of both the ARDL and ECM studies of the third model show that the independent variables: energy consumption, foreign direct investment, gross capital creation, and public debt account for over 99 percent of the variance in the dependent variable (Environmental Degradation – ED). The results imply that whilst Industrialization (IN) and Gross Domestic Product (GDP) help to reduce Environmental Degradation (ED), Energy Consumption (EC), the number of Registered Vehicles (NV), and Population (POP) aggravate it.

With a documented increase of 2.19 units, clearly showing a statistically significant association, Energy Consumption clearly influences Environmental Degradation.

Environmental damage is much exacerbated by even a little rise in energy demand. For energy generation, Pakistan mostly depends on fossil fuels including coal, oil, and natural gas, which releases greenhouse gases (GHGs) hence aggravating air pollution and climate change. It also shows a statistically significant rise in environmental damage for every unit increase in registered vehicles—0.0013 units. In automobiles, combustion engines spew pollutants including carbon monoxide (CO), nitrogen oxides (NOx), particulate matter (PM), and volatile organic compounds (VOCs), therefore aggravating human health problems and poor air quality. Pakistan must encourage sustainable mobility options including electric cars, public transit, tighter emission rules, and alternative fuels if it is to meet these problems. Though to less of a degree (0.0048 units), population increase also fuels environmental damage. Pakistan's fast growing population pressures its natural resources, causing depletion, soil erosion, and deforestation.

Urbanization aggravates these problems, causing habitat invasion, more energy usage, and more pollution. Larger population of Pakistan aggravates its sensitivity to climate change by increasing the impact of phenomena linked to it like floods, droughs and heat waves. Against expectations in a nation like Pakistan with low utilization of green energy at the commercial level, the data reveal shockingly a statistically insignificant negative association between industrialization and environmental damage. Industrial modernization, acceptance of advanced technologies, and application of waste management techniques and cleaner manufacturing methods could all help to explain this negative link. Good implementation of environmental rules helps businesses to adopt better methods, so promoting their reduction of environmental damage. The results imply that a unit rise in GDP translates into a 0.0039 unit decrease in environmental degradation. Economic development, industrial output, and environmental damage have complex interactions driven by many elements including government regulations, environmental consciousness, and economic activities. Reducing environmental damage in Pakistan depends on a complete strategy that strikes a mix between environmental sustainability and economic development.

Serial correlation

We will explore the field of serial correlation in looking at the given model for possible correlations between errors. Serial correlation differs from independent mistakes, which are sometimes taken for granted in regression analysis in that it involves a link between errors across observations. Model misspecification, non-random data patterns, and errors in the definition of the regression error term are among the several causes from which this phenomena can develop. Positive and negative forms are two varieties of serial correlation. Positive serial correlation is the phenomenon whereby errors in consecutive observations show a tendency to be associated, implying that a positive error in one period increases the likelihood of another positive error in the next period, and versa for negative errors. Conversely, negative serial correlation suggests that a positive error in one observation increases the likelihood of running into a negative error in another, and vice versa.

Although serial correlation uses the F-statistic to affect the evaluation of total regression significance even if it does not directly bias estimates of the regression coefficient. Positive serial correlation often inflates Type I errors, which could cause false null hypothesis rejection. On the other hand, negative serial correlation might lower the F-statistic and raise the danger of Type II errors by not rejecting the null hypothesis when it turns out to be wrong.

Moreover, positive serial correlation might affect the estimate of ordinary least squares standard errors for regression coefficients, hence producing often understated standard errors and inflated significance levels for related t-statistics. This influences several statistical tests including significance tests, confidence intervals, and hypothesis tests concerning individual coefficients. Negative serial correlation likewise influences statistical significance and standard errors but in the other manner.

Serial Correlation LM Test

We may find whether the model exhibits serial correlation by use of the coefficient diagnostics serial correlation LM test. This test searches residuals of a regression model for the existence of serial correlation based on three delays as indicated by the VAR lag length criterion for our third model.

In this context, the Lagrange Multiplier (LM) test serves as a statistical tool aiming to find any consistent trends or linkages among the residuals. Such patterns would question the fundamental idea of independence of errors, which underlie the conventional linear regression model. The LM test will enable us to ascertain whether there is a clear serial connection among the residuals, so perhaps undermining the validity of the regression analysis results. Maintaining the dependability and strength of the model depends totally on this diagnostic test identifying and correcting any violations of the independence of mistakes assumption.

Breusch-Godtrey Serial Correlation LM Test:

Null hypothesis: No serial correlation at up to 3 lags

F-statistic	0.583892	Prob. F(3,10)	0.6390
Obs*R-squared	6.111364	Prob. Chi-Square(3)	0.1063

Resuals—the variations between the observed values and the values the model predicts—are derived following a fit of a regression model to the data. The LM test looks at residuals for correlation at several lags—that is, times intervals. It investigates if the residuals at one time point have any bearing on those residuals at another time point.

The test offers vital values to evaluate the alternative hypothesis of serial correlation versus the null hypothesis of none. The LM test has as its null hypothesis no serial correlation in the residuals. Stated differently, the mistakes have autonomous character. Should the probability value be 5% we reject the null hypothesis and embrace the alternative hypothesis of serial correlation. On the other hand, should the probability value be more than 5%, we embrace the null hypothesis and reject the alternative one about serial correlation.

F (3, 21) has a likelihood of showing no serial association since 0.63 is above 0.05 (5%). We shall so perform the stability diagnosis to test the stability.

Heteroskedasticity Test

We used the Breusch-Pagan-Godfrey heteroskeasticity test to find whether the variance of errors stays constant, therefore demonstrating homoskeasticity in the model. This test seeks to find whether the variance of the error term in our first model stays constant over all degrees of the independent variables.

We are essentially looking at whether changes in the values of the independent variable(s) affect the spread or dispersion of the residuals—that is, the differences between observed and expected values. By evaluating the stability of error variance, this study guarantees the dependability of the regression model—a necessary condition for correct estimate interpretation of coefficients. Regressing the squared residuals from the initial regression model on the independent variables forms the basis of the Breush-Pagan-Godfrey heteroskedasticity test. The null hypothesis is homoskeasticity—that the residual variance is constant.

Heteroskedasticity Test: Breusch-Hagan-Godtrey
Null hypothesis: Homoskedasticity

F-statistic	1.615870	Prob. F(27,13)	0.1827
Obs*R-squared	31.58778	Prob. Chi-Square(27)	0.2477
Scaled explained SS	4.553307	Prob. Chi-Square(27)	1.0000

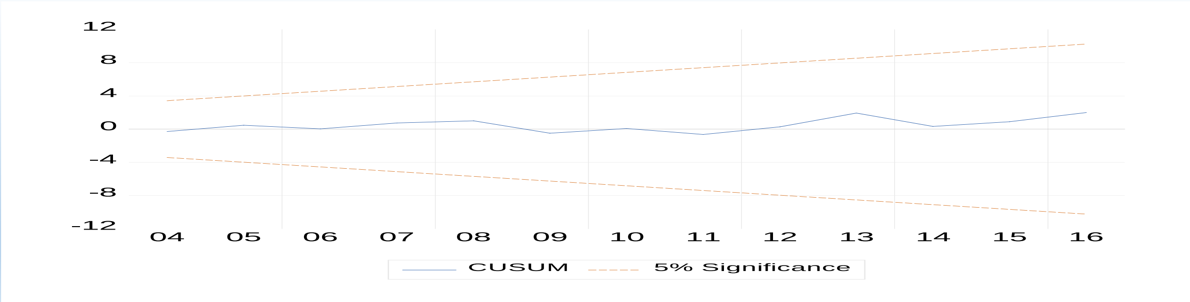
Consequently, we reject the null hypothesis of homoskedasticity and embrace heteroskeasticity if the probability value is 5% or less than that. The F-statistic probability of the test reveals in our model 0.1827 (above 0.05). Thus, it is determined that our model does not show heteroskedasticity as we cannot reject the null hypothesis of homoskeasticity.

Stability Analysis

Last but not least, the stability test evaluates whether the statistical characteristics of the model hold constant throughout time. We particularly use recursive estimation under consideration of the CUSUM output criterion.

Examining the stability of model parameters over several time periods is much aided by recursive estimates. It permits constant changes in parameter estimates depending on evolving system dynamics and data trends. This approach adapts to variations and uncertainty thereby guaranteeing that the model stays dependable and efficient.

The CUSUM test shows that the model stays constant; so, the stability falls within the reasonable range of 5%.



DISCUSSION AND CONCLUSION

With an eye toward the effects of industrialization, population increase, energy consumption, and car registration, the study looks at environmental damage in Pakistan. Driven by industrialization and population development, economic growth increases energy demand—mostly from fossil fuels—which feeds major environmental problems including deforestation, air and water pollution, and greenhouse gas emissions. Emphasizing the importance of sustainable energy practices, the research investigates the intricate interactions between economic growth, energy use, and environmental degradation using ARDL and ECM methodologies. Notwithstanding differences in the outcomes of several econometric models, the study offers understanding of the bidirectional relationships among these factors and emphasizes the need of strategic measures to combine environmental sustainability with economic development in Pakistan.

The paper looks at how Environmental Degradation (ED) in Pakistan is influenced by Energy Consumption (EC), Gross Domestic Product (GDP), the Value Index of Industrialization (IN), the count of Registered Vehicles (NV), and Population (POP).

The bound tests—F-Bound test and t-Bound test—show mixed results using the unconstrained constant and "No Trend Model". While the absolute value of the t-bound statistic (-3.3) is less than the I-0 bound value (-2.57), the F-Bound test reveals that the absolute value of the F-bound statistic (4.29) surpasses the bound value. Consequently, despite the t-statistic test reveals no such association, the F-Bound test shows cointegration and a long-term relationship between the variables.

Establishing ARDL-based cointegration in the third model gets complicated by this difference. The study uses both ARDL and ECM approaches as a solution to examine short- and long-term correlations. Energy consumption, industrialization, GDP, and other factors account for approximately 99% of the variance in Environmental Degradation (ED). Important findings show that energy use significantly affects ED with a value of 2.19 units, meaning that a one-unit rise in energy consumption dramatically aggravates environmental damage. Dependency of Pakistan on coal, oil, and natural gas fuels adds to greenhouse gas emissions and aggravation of air quality. Reducing these effects calls for switching to renewable energy sources. Every unit increase in registered automobiles helps to generate a 0.0013 unit increase in ED. Pollumes released by vehicles compromise human health and worsen air quality. Pakistan must thus encourage electric cars, improve public transportation, and enforce stronger emission rules if it is to solve issue. 0.0048 units in ED per unit increase in population represents a statistically significant but small increase. Fast population increase stresses natural resources and drives urbanization, hence increasing environmental pressure and pollution levels. The study reveals shockingly a statistically negligible detrimental link between industrialization and ED. This could result from technological developments and industry-adopted greener manufacturing techniques over the course of the research period. Good environmental rules and industry-driven sustainability projects could help to explain this surprising outcome. An rise in GDP one unit yields a 0.0039 unit drop in ED. Economic development and environmental damage have a complex relationship driven by elements including economic activity, policies, and environmental consciousness. Therefore, a balanced approach including environmental sustainability is required.

Pakistan has to make investments in green technologies, renewable energy, and energy-efficient methods if it is to slow down environmental deterioration. Policymakers are encouraged to help the shift to renewable energy to satisfy growing energy needs sustainably and lower CO2 emissions, therefore supporting general sustainable economic development.

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APPENDICES

Appendix I

Log Likelihood by Rank (rows) and Model (columns)					
0	-2721.490	-2721.4	-2717.577	-2717.577	-2706.13
1	-2689.204	-2688.96	-2685.05	-2680.94	-2669.722
2	-2669.949	-2669.43	-2665.70	-2657.76	-2647.727
3	-2658.685	-2656.49	-2652.80	-2644.57	-2636.911
4	-2653.284	-2646.75	-2643.30	-2634.75	-2630.301
5	-2650.413	-2642.07	-2641.12	-2628.14	-2626.030
6	-2650.362	-2639.89	-2639.8	-2626.0	-2626.018
Akaike **Information** Criteria by Rank(rows) and Model (columns)					
0	128.2553	128.2553	128.3524	128.3524	128.0994
1	127.3118	127.3470	127.3978	127.2535	126.9638
2	126.9744	127.0433	127.0561	126.7796	126.4989
3	127.0086	127.0464	127.0140	126.7710	126.5540
4	127.3155	127.1980	127.1303	126.9187	126.8047
5	127.7401	127.5850	127.5870	127.2160	127.1642
6	128.2959	128.0883	128.0883	127.7218	127.7218
Schwarz Criteria by Rank (rows) and Model (columns)					
0	129.7298	129.7298	130.0727	130.0727	130.0654
1	129.2778*	129.3540	129.6095	129.5062	129.4213
2	129.4318	129.5827	129.7593	129.5648	129.4479
3	129.9576	130.1183	130.2088	130.0886	129.9945
4	130.7560	130.8023	130.8166	130.7688	130.7367
5	131.6721	131.7217	131.7648	131.5985	131.5876
6	132.7194	132.7575	132.7575	132.6368	132.6368

Appendix II

Standard errors in ( ) & t-statistics in [ ]

	ED
ED(-1)	-0.157616 (0.15975) [−0.98661]
$ED(-2)$	0.291392 (0.09791) [2.97607]
C	−9422,226 (438731) [−2.14761]
GDP	-0.000354 (0.00020) [−1.77452]
EC	1.410927 (0.30204) [4.67130]
IN	389.0207 (46.9231 [8.29059]
NV	0.000554 (0.00037) [1.49017]
POP	−5.24E − 05 (0.00012) [−0.45262]

Appendix III

Selected Model: ARDL 4, 4, 4, 4, 2, 4

Variable	Coefficient	Std. Error	t-Statistic	Prob.*
ED(-1)	0.399334	0.263293	-1.516693	0.1533
ED(-2)	0.355117	0.352450	1.007566	0.3320
ED(-3)	-0.564332	0.315515	-1.788604	0.0970
ED(-4)	-0.941739	0.425580	-2.212836	0.0454
EC	2.191538	0.607514	3.607386	0.0032
EC(-1)	-0.768240	0.684941	-1.121614	0.2823
EC(-2)	1.289192	0.769937	1.674413	0.1179
EC(-3)	1.519685	0.842754	1.803237	0.0946
EC(-4)	0.718707	0.672569	1.068600	0.3047
GDP	-0.003945	0.001948	-2.025469	0.0639
GDP(-1)	-0.002975	0.001736	-1.713528	0.1103
GDP(-2)	-0.008048	0.003288	-2.447416	0.0294
GDP(-3)	0.012454	0.010063	1.237611	0.2377
GDP(-4)	0.009919	0.008578	1.156272	0.2684
IN	-74.51207	276.6951	-0.269293	0.7919
IN(-1)	488.0074	240.1599	2.032010	0.0631
IN(-2)	163.2605	235.1514	0.694278	0.4997
IN(-3)	328.5958	177.7731	1.848400	0.0874
IN(-4)	215.0833	223.9542	0.960390	0.3544
NV	0.001316	0.000532	2.474948	0.0279
NV(-1)	0.002242	0.001239	1.809288	0.0936
NV(-2)	0.002683	0.001029	2.607139	0.0217
POP	0.004872	0.001297	3.757519	0.0024
POP(-1)	-0.008831	0.002906	-3.038939	0.0095
POP(-2)	0.004338	0.003571	1.214643	0.2461
POP(-3)	0.002371	0.003665	0.646959	0.5289
POP(-4)	-0.003836	0.002170	-1.768055	0.1005
C	3107.219	13086.79	0.237432	0.8160

Appendix IV

Conditional Error Correction Regression

Levels Equation

Case 3: Unrestricted Constant and No Trend!

Variable	Coefficient	Std. Error	t-Statistic	Prob.
EC	1.947304	0.214014	8.906022	0.0000
GDP	0.002969	0.001933	2.315465	0.0033
IN	439.6575	54.74112	8.461697	0.0000
NV	0.002439	0.001260	2.886631	0.0380
POP	-0.000426	0.000155	-2.637544	0.0166

Null Hypothesis: No levels relationship

F-Bounds Test

Test Statistic	Value	Signif.	I(0)	I(1)
Asymptotic: n=100				
$F_K^{S\text{-}statstic}$	4.298660	10%	2.26	3.35
	5	5%	2.62	3.79
		2.5%	2.96	4.18
		1%	3.41	4.68

Null Hypothesis: No levels relationship

t-Bounds Test

Test Statistic	Value	Signif.	I(0)	I(1)
Asymptotic: n=100				
t-statistic	-3.337470	10%	-2.57	-3.86

	5%	-2.86	-4.19
	2.5%	-3.13	-4.46
	1%	-3.43	-4.79

Appendix V

ECM Regression

Case 3: Unrestricted Constant and No Trend

Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
C	3107.219	1513.018	2.053656	0.0607
D(ED(-1))	1.150953	0.349023	3.297642	0.0058
D(ED(-2))	1.506070	0.373790	4.029187	0.0014
D(ED(-3))	0.941739	0.279104	3.374149	0.0050
D(EC)	2.191538	0.349450	6.271398	0.0000
D(EC(-1))	-3.527584	0.718758	-4.90788	0.0003
D(EC(-2))	-2.238392	0.782368	-2.86104	0.0134
D(EC(-3))	-0.718707	0.453086	-1.58625	0.1367
D(GDP)	-0.003945	0.000918	-4.29580	0.0009
D(GDP(-1))	-0.014325	0.002408	-5.94993	0.0000
D(GDP(-2))	-0.022373	0.003919	-5.70880	0.0001
D(GDP(-3))	-0.009919	0.004019	-2.46775	0.0283
D(IN)	-74.51207	128.1774	-0.58132	0.5710
D(IN(-1))	-706.9396	206.3656	-3.42566	0.0045
D(IN(-2))	-543.6791	124.9462	-4.35130	0.0008
D(IN(-3))	-215.0833	131.8090	-1.63178	0.1267
D(NV)	0.001316	0.000318	4.138541	0.0012
D(NV(-1))	-0.002683	0.000566	-4.73946	0.0004
D(POP)	0.004872	0.000974	5.001777	0.0002
D(POP(-1))	-0.002873	0.001519	-1.89145	0.0811
D(POP(-2))	0.001465	0.001592	0.920320	0.3742
D(POP(-3))	0.003836	0.001305	2.939681	0.0115
CointEq(-1)*	-2.550287	0.426759	-5.97594	0.0000