



**Emission Paradox Unraveling The Interplay Between Economic
Growth And Environmental Sustainability In Pakistan**

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Abstract

This study examines the dynamic relationship between the emission of carbon dioxide (CO₂) and some of the important macro-economic, structural, and demographic factors in Pakistan from 1970 to 2023 using Autoregressive Distributed Lag (ARDL) bounds testing approach. The analysis includes three structural specifications industry, agriculture and services as this captures sectoral heterogeneity in emissions behavior. The results confirm the existence of long-run cointegration between CO₂ emissions, GDP, GDP, energy consumption, trade openness and population density. The long-run coefficients are estimated and reveal that the GDP has a positive relationship with the emission and the squared term of the GDP has a negative relationship with the emission which validates the Environmental Kuznets Curve hypothesis. Energy consumption is the single biggest driver of emissions in all models and industrial and agricultural activities increase environmental degradation. However, the services sector has the lowest emission elasticity, indicating its potential for facilitating decarbonization in the long run. Trade openness does not have a clear impact but rather mixed effects on emissions, since in the industrial model emissions are lowered, while in the agricultural and services sectors emissions rise. Error correction terms are negative and significant under all models and suggest stable adjustment to equilibrium. The results highlight the importance of clean energy transitions, sustainable industrial restructuring and environmental policies that are ecosystem-specific in order to balance economic growth and sustainability in Pakistan.

Keywords: Economic Growth, CO₂ Emissions, Environmental Kuznets Curve, Structural Transformation, Pakistan

Table of Contents

Abstract	ii
Table of Contents	iii
List of Figures	vii
List of Tables	viii
Chapter 1: Introduction	1
1.1 Background of the Study	1
1.2 Problem Statement	2
1.3 Research Questions	3
1.4 Research Objectives	3
1.5 Significance of the Study	4
1.6 Scope and Limitations	6
Chapter 2: Literature Review	9
2.1 Theoretical Background and Framework	9
2.1.1 Theoretical Background	9
2.1.2 Environmental Kuznets Curve Theory	10
2.1.3 Structural Change Hypothesis and Environmental Outcomes	10
2.1.4 Trade Openness, Energy Systems, and Emissions	11
2.1.5 Energy Output Emissions Framework	11
2.1.6 Integrated Theoretical Framework of the Study	12

2.2 Empirical Literature	13
2.3 Research Gap.....	17
Chapter 3: Methodology	21
3.1 Introduction	21
3.2 Data and Variable Description.....	21
3.3 Model Specification	22
3.4 Stationarity Testing.....	23
3.5 ARDL Bounds Testing for Cointegration.....	24
3.6 Long-Run ARDL Estimation.....	24
3.6.1 Industry-based model (IND)	24
3.6.2 Agriculture-based model (AGR)	25
3.6.3 Services-based model (SER).....	25
3.7 Error-Correction Model (ECM)	26
3.8 Diagnostic Testing.....	26
3.9 Graphical Representation	27
3.10 Interpretation of Relationships	27
3.11 Summary of Methodology.....	28
Chapter 4: Results and Discussion	30
4.1 Introduction	30
4.2 Descriptive Statistics.....	31

4.2.1 Summary of Variables	31
4.2.2 Interpretation of Distributional Properties	33
4.3 Stationarity Tests	34
4.3.1 Augmented Dickey–Fuller Results at Levels	34
4.3.2 Augmented Dickey–Fuller Results at First Difference	36
4.3.3 Implication for ARDL Application.....	37
4.4 ARDL Bounds Test for Cointegration.....	37
4.4.1 Bounds Test: Industry Model	38
4.4.2 Bounds Test: Agriculture Model	38
4.4.3 Bounds Test: Services Model.....	38
4.4.4 Interpretation of Cointegration.....	39
4.5 Estimated Long Run ARDL Coefficients.....	40
4.5.1 Industry-Based Long Run Model.....	40
4.5.2 Agriculture-Based Long Run Model	42
4.5.3 Services-Based Long Run Model.....	43
4.5.4 Comparison Across Structural Models.....	44
4.6 Short Run Dynamics: Error Correction Model	45
4.6.1 Industry Model ECM	46
4.6.2 Agriculture Model ECM.....	46
4.6.3 Services Model ECM	46

4.6.4 Interpretation of Adjustment Speeds	47
4.7 Discussion of Results in Light of Recent Literature	47
4.8 Diagnostic and Stability Tests	48
4.8.1 Serial Correlation Test.....	49
4.8.2 Heteroskedasticity Test.....	49
4.8.3 Normality Test.....	50
4.8.4 Stability Tests (CUSUM and CUSUMSQ)	50
4.9 Graphical Presentation of Results	51
4.9.1 Actual vs. Fitted CO ₂ Emissions	51
4.9.2 Long Run Coefficient Comparison Charts.....	51
4.9.3 Residual Stability Graphs.....	53
4.10 Summary of Empirical Findings	55
Chapter 5: Discussion	56
5.1 Policy Recommendations.....	62
Conclusion.....	64
References	65

List of Figures

Figure 1: Environmental Kuznets Curve and Related Factors	16
Figure 2: ADF Level Test Comparison	35
Figure 3: Comparison of Bounds Test F Statistics	39
Figure 4: Long Run Elasticities in the Industry Model (ASCII Bar Plot).....	42
Figure 5: Comparison of Sectoral Coefficients in Agriculture Model (ASCII Plot)	43
Figure 6: Comparison of Long Run Elasticities Across Models.....	45
Figure 7: Error Correction Term Magnitudes Across Models.....	47
Figure 8: Actual vs. Fitted CO ₂ Emissions (ASCII Line Plot).....	51
Figure 9: Long Run Coefficients – Industry Model (ASCII Bar Plot).....	52
Figure 10: Long Run Coefficients – Agriculture Model	52
Figure 11: Long Run Coefficients – Services Model.....	53
Figure 12: CUSUM Stability Plot (ASCII View).....	54
Figure 13: CUSUMSQ Stability Plot.....	54

List of Tables

Table 1: Descriptive Statistics of the Study Variables.....	31
Table 2: Summary of Central Tendency and Dispersion.....	32
Table 3: Skewness and Kurtosis Comparison	33
Table 4: Correlation Snapshot Among Select Variables.....	34
Table 5: ADF Test Statistics at Levels for All Variables	35
Table 6: ADF Test Statistics at First Difference for All Variables.....	36
Table 7: Summary of Integration Orders.....	36
Table 8: Bounds Test Results for Industry Model.....	38
Table 9: Bounds Test Results for Agriculture Model	38
Table 10: Bounds Test Results for Services Model.....	38
Table 11: Long Run Coefficients of the Industry-Based ARDL Model.....	40
Table 12: Long Run Coefficients of the Agriculture-Based ARDL Model.....	42
Table 13: Long Run Coefficients of the Services-Based ARDL Model	43
Table 14: Comparative Long Run Elasticities Across IND, AGR, and SER Models	44
Table 15: Breusch–Godfrey LM Serial Correlation Test	49
Table 16: ARCH Heteroskedasticity Test Results.....	49
Table 17: Jarque–Bera Normality Test.....	50

Chapter 1: Introduction

1.1 Background of the Study

In recent decades, the world has experienced rising issues brought by climate change, with carbon dioxide (CO₂) emissions from fossil fuel burning, deforestation and industry becoming the main factors of global warming (Adeel et al., 2024). The buildup of CO₂ in the atmosphere traps infrared radiation resulting in the greenhouse effect which increases average global temperatures and disrupts precipitation cycles, leading to extreme weather events, and has negative impacts on ecosystems (Li, Liu, & Ali, 2024). These environmental changes impose economic and social costs in terms of depressed agricultural production, infrastructure damage, health burden and forced migration, especially in the vulnerable regions.

The tension between economic growth and environmental sustainability has become more acute in the 21st century thus leading to what might be termed the emission paradox. As economies grow, energy use grows often based on carbon intensive energy sources increasing emissions as well as the degradation of the environment. Yet modern developmental objectives require both an increase in the standard of life and a greener way of life. In poorer nations, the situation is even more acute as growth is often tied to the infrastructures and the industrialization that use fossil fuels and thus decoupling of emissions and growth is not easy. The central issue is whether the fundamental goal of economic growth is inexorably at odds with the environmental quality or whether structural transformations, technology adoption, and policy interventions can bring the two objectives in one. The central question is whether economic growth is fundamentally incompatible with the quality of the environment or whether structural transformations, technology adoption and policy interventions can reconcile the two objectives (Li et al, 2024; Adeel et al, 2024).

In Pakistan, the emission paradox is particularly high. The country is still largely reliant on non-renewable energy sources such as coal, natural gas, and oil while renewables

(solar, wind, hydropower) are still contributing a small portion of the energy mix (Li et al., 2024). This reliance limits the ability to re-equip towards pathways that are cleaner. At the same time Pakistan is witnessing a rapid industrialization and urbanization due to population growth, infrastructure expansion and industrial policies. Urban centers are using more energy, more cars, and industrial fumes. Concurrently, Pakistan is also suffering from environmental degradation air pollution, water scarcity, land degradation, deforestation and climate vulnerability with Pakistan being high on the list of countries affected by floods, heat waves, glacial melt and changing monsoon patterns (Waheed, 2025). The co-existence of developmental imperatives and fragile environmental systems underlines the need to explore the issue of sustainable management of growth in Pakistan.

1.2 Problem Statement

Pakistan has enjoyed a steady economic growth in the last few decades due to increased energy use, population growth and sectoral change. However, this growth has been accompanied by a consistent growth in carbon dioxide emissions and environmental degradation. This simultaneous co-existence of economic development and worsening of environmental quality raises an important issue about sustainability of the development trajectory in Pakistan.

Environmental Kuznets Curve hypothesis is a hypothesis which describes a non-linear relationship between income and environmental degradation, implying that emissions rise during the early stages of development and fall after some threshold of income. While this hypothesis has been put to test extensively in the developed and developing economies, empirical evidence is mixed and inconclusive for Pakistan. Some existing studies tend to focus on growth emissions nexus, largely from the perspectives of income and energy consumption, and ignore the role of structural change, trade openness and demographic pressure in a comprehensive analytical framework.

Pakistan economy has experienced gradual changes in its structural transformation through different types of shifts in the sector of agriculture, industry, and services. Each of these sectors have different energy uses and different emission intensities, which

means that aggregate growth based analyses may disguise important sector specific dynamics. As a result, growing integration of trade, and growing population density also further complicate the relationship between economic growth and environmental outcomes. The lack of integrated, sector based empirical analysis means it is difficult to devise effective policies to balance growth and environmental sustainability.

Therefore, the main issue that is worked upon in this research is the deficiency of comprehensive empirical evidence regarding the joint relationship between economic growth, energy consumption, structural change, trade openness, and population density with carbon dioxide emissions in Pakistan. By using an extended Environmental Kuznets Curve framework and sector specific econometric models, the present study attempts to shed more light on the question as to whether the growth path of Pakistan can switch towards long run environmental sustainability.

1.3 Research Questions

1. What is the long-run relationship between economic growth and CO₂ emissions in Pakistan?
2. How do energy consumption, trade openness, population density, and structural change affect environmental sustainability?
3. Does Pakistan's development follow the Environmental Kuznets Curve (EKC) hypothesis?
4. What are the causal relationships among economic growth, energy use, and emissions?

1.4 Research Objectives

- To analyze the long-run and short-run dynamics between CO₂ emissions and key macroeconomic variables.
- To test the existence of the EKC hypothesis in Pakistan.

- To assess the role of structural change, trade openness, and population density in influencing environmental quality.
- To recommend sustainable policy pathways for balancing growth with environmental protection.

1.5 Significance of the Study

This results make substantive contribution to the empirical literature on the relationship between economic growth and environmental sustainability by extending the conventional Environmental Kuznets Curve (EKC) methodology to take into account structural change and demographic dimensions in a unified model. The traditional EKC suggests an inverted-U behavior between income and emission yet empirical studies have been volatile to model and variables specification as well as dissimilarity among nations. Recent research highlights the faulted results of not taking sectoral make-up and population dynamics into account (Jaeger, 2023; Wang et al., 2021). By explicitly incorporating the share of value added by industries (as a measure of structural transformation) and population density (to capture demographic pressure), the present research enhances the EKC framework and enables one to parse out the scale, composition and technique effects more finely over time.

In the context of Pakistan, empirical research shows that the key drivers behind the dynamics of emissions are structural realignment and population expansion, but these are rarely incorporated into growth-emissions modeling at the same time. Decomposition analyses are used to attribute a significant part of Pakistan's emissions increase in history to increasing output and population while the improvement from technological change and energy efficiency has only partially compensates it (Raza & Dongsheng, 2023). Other work finds that the industrial and power generation sectors are at the center of driving emissions volatility with electricity dispatch patterns, fuel mix and demand fluctuations influencing the long-run carbon outcomes (Khaliq et al., 2024). However, in the case of existing models, the structural change itself and the population effects often do not form part of a more fundamental interacting determinations of the. This research fills this gap by taking both dimensions as endogenous and interactive

driving forces influencing CO₂ emissions and through so doing, deliver a more holistic understanding regarding trajectory of Pakistan's emissions.

The methodological significance is interesting also. This study uses an EKC model which includes energy consumption, trade openness, structural change and demographic pressure apart from income and its square estimated using cointegration techniques suitable for variables of mixed integration orders and possible structural breaks. Such an approach is helpful in improving the causal clarity making the difference between the long run equilibria and short run adjustments and in reducing the omitted variable bias that might conceal the turning point of the EKC. Inclusion of trade openness in the model is particularly important in Pakistan case as the trade regime can facilitate the low carbon technologies diffusion or can amplify the pollution through the relocation of emission intensive production. The direction and magnitude of the effect of trade is strongly dependent on the domestic regulatory environment and the composition of the industry (Wang et al., 2021). A sensible assessment of the impact of trade in the context of Pakistan can help to understand the relevance of openness with respect to the contribution of emissions reduction potential of growth policies.

On the practical policy front, this study comes at a time and is relevant to the development vision and the climate commitments of Pakistan. First, national planning can be informed by the mapping of the influence of structural changes in GDP share on the path of emissions on the agenda of countries in order to focus on the cleaner expansion in sectors. The long-term development strategies by Pakistan lay focus on structural change under the abandonment of low productivity agriculture and the adoption of manufacturing and services; under quantification of carbon implications of the change, giving sectoral priorities enhances the argument in support of sectoral priorities. Second, the results provide direct feedback to Pakistan's responsibilities as part of the Sustainable Development Goals (SDGs). Specifically, the analysis is related to SDG 8 (sustained, inclusive growth), SDG 9 (industry, innovation and infrastructure), SDG 11 (sustainable cities and communities) and SDG 13 (climate action). The study also provides arguments in favor of integrated policy design, which is the alignment of economic and environmental goals by description of the emissions impact of growth

drivers. Third, the study gives insight for calibrating Pakistan's climate mitigation strategies embedded in the form of its nationally determined contributions (NDCs). By determining the structural levers that have the most potential of abatement, going beyond merely cutting the use of coal or increasing the use of renewable resources, cost-efficient approaches to achieving the emissions target without compromising on growth are identified.

Finally spanning the period from 1970 to 2023, the study makes it possible to identify long-term structural breaks, regime shifts and turning points in the growth- emissions nexus. This long horizon allows the model to take into account significant policy changes, energy price shocks as well as changes in energy infrastructure. According to the forecasting literature, the emissions trajectory in Pakistan is non-linear with sudden shifts in technology or change in policy regimes and, thus, long panels are necessary to have a solid inference on turning points (Iftikhar et al., 2024). The complexity of the structure and time-scale of this model puts the research to provide plausible estimates of whether or not Pakistan is in a turning point or has already reached one and whether future development will see no constraints in decoupling growth and emissions under plausible structural and demographic paths.

1.6 Scope and Limitations

The empirical analysis is limited to Pakistan and the years 1970-2023 are used as the annual data. This researches longitudinally so that it is possible to observe multiple phases of economic growth, energy policy changes, industrial restructuring, and demographic trends. The dependent variable is cells of CO₂ emissions, in the unit of metric tons per capita, that is currently used in many contexts as an indicator of carbon pressure at the national scale and as a synonym of the climate accounting (Raza & Dongsheng, 2023; Reynalte-Tataje et al., 2024). While recognizing that carbon emissions are just one facet of environmental quality, the emphasis on CO₂ makes the study fit in with the SDG 13 and Pakistan's NDC reporting mechanism.

The explanatory variables are real GDP per capita and square of real GDP per capita to check for nonlinearity, energy consumption per capita to encapsulate the intensity effect,

trade openness as total trade to GDP to capture the effect of external linkages, industry value added (as a share of GDP) to capture structural change and population density to capture the effect of demographic and spatial concentration pressures. This configuration enables to decompose emissions dynamics in terms of scale, composition and demographic pressure channels. Employing industry value added as a structural proxy is also compatible with what has been published relating shifts in the composition of industries to emissions trajectories (Raza et al., 2023; Wang et al. 2021). Population density offers a parsimonious measure of the intensity of energy demand across spatial distribution, though it cannot fully capture urban form or infrastructure variation (Amin et al., 2023).

Despite its advantages, this design admits several limitations. Firstly, restricting environmental degradation to per capita CO₂ overlooks other pollutants (e.g., particulate matter, NO_x, sulfur oxides), ecological degradation, and multi-dimensional sustainability indicators. Emissions effects for air quality or biodiversity may diverge from carbon trends observed here. Secondly, the proxy of aggregate industry share does not distinguish among sub-sectors; energy-intensive manufacturing, heavy industry, and light industry may have heterogeneous carbon responses that aggregate proxies smooth over (Raza & Yousaf, 2025). Third, trade openness measured as trade-to-GDP ratio abstracts from product composition, carbon embodied in trade, and the direction of trade flows. Without disaggregated trade data, the model cannot detect whether openness leads to cleaner imports or pollution-intensive exports. Fourth, population density is a coarse demographic metric that fails to capture intra-urban structure, household energy behavior, or infrastructure access, all of which mediate energy demand and emissions (Amin et al., 2023). Fifth, although use of cointegration methods with error correction dynamics mitigates endogeneity concerns by separating long-run and short-run variation, fully exogenous causality inferences are constrained. Feedback effects among growth, energy, and emissions may still persist beyond what standard time-series methods can isolate. Sixth, structural break tests and stability diagnostics help address regime shifts, but abrupt or unknown non-linear shifts may remain unmodeled. External shocks such as energy crises, policy reversals, or climate extreme events may induce dynamics that exceed the capacity of linear models to capture (Song, 2021). Finally, the

generalizability of results is confined by Pakistan's specific institutional, resource, and geographic context; the turning point estimates or structural coefficients here may not directly transfer to other developing nations with different energy endowments, policy regimes, or demographic trajectories.

In sum, this work manages a trade-off between general and parsimonious scale: to focus on the case of Pakistan and a long time, and by building a structurally-enriched EKC model, versus the limitations and senses of carbonites of measurement, aggregate proxies, and identification of a time series. The findings will thus provide strong, but contextual, cross-country information on the emission paradox in Pakistan and the possibilities for sustainable growth in the context of structural transformation combined with demographic pressure.

Chapter 2: Literature Review

2.1 Theoretical Background and Framework

This section introduces the theoretical background underlying the analysis of the link between economic growth and environmental sustainability. The research draws upon known and recent theories in environmental economics, development economics and energy economics to build an integrated analytical framework. Specifically, the following hypotheses are combined: the Environmental Kuznets Curve hypothesis, Structural Change Theory, Energy-Output-Emissions framework, trade openness and demographic pressure theories, in order to explain the relationship between economic growth and carbon emission over time. Integrating these perspectives enables the understanding of the mechanism expressing the effect of scale, composition and technique in developing economies like Pakistan (Luzzati et al., 2018).

2.1.1 Theoretical Background

The theoretical background of growth-environment interactions relates to the wider debate on whether economic development is inevitably associated with environmental degradation or whether economic development can eventually promote environmental improvement. Early theories of development were dominated by the scale effects of growing production and consumption, where higher energy demand and emissions increase as a result. More recent frameworks emphasize that environment results not from income growth but from structural transformation, technological advancement and policy changes. Modern environmental economics is an approach that acknowledges that economic growth influences emissions in various ways. These include changes in the structure of production, energy intensity, technological innovation and institutional quality. Theoretical models emphasize to an increasing extent that sustainability of the environment is not dependent on how rapidly economies grow, but how they grow. Consequently, integrated frameworks that meld growth theory with sectoral dynamics

with regard to energy systems have actually become at the very centre of modern environmental analysis (Yan et al., 2022).

2.1.2 Environmental Kuznets Curve Theory

The Environmental Kuznets Curve theory assumes an inverted U of the relationship between environmental degradation and income per capita. At the initial stages of development, economic growth causes an increase in emissions as a result of industrialization, urbanization and dependence on fossil fuels. Above a certain level of income, however, further growth is linked to decreasing emissions as economies transition to cleaner technologies and move to services, and to more stringent environmental regulations.

While EKC evidence has been widely documented, recent theoretical and empirical studies underscore the fact EKC behavior is not universal. Turning points differ in the different countries depending on the energy structure, sectoral composition and the quality of institutions (Stern, 2017). Fossil fuel dependent economies are likely to have delayed or weak EKC turning points especially when industrial activity is still dominant. These insights imply that the outcomes of EKC are conditional as opposed to automatic and supports the need to explicitly model energy use and structural change.

2.1.3 Structural Change Hypothesis and Environmental Outcomes

Structural Change Theory is a theory of structural change and its impact on environmental performance as development proceeds. Early stages of development are defined by the shift from agriculture to industry resulting in emissions from energy intensive manufacture and transportation. As development advances, economies are typically shifting to service, which are typically less carbon intensive per unit of output (Sergioet al. 2023).

The environmental implications of structural change are thus dependent on the speed with which this sectoral reallocation takes place and the direction of change. According

to empirical and theoretical research, decoupling of emissions from output is facilitated by service led growth, combined with clean energy use adoption. On the other hand, industrial dominance for longer periods of time can outweigh the benefits of technological improvements and slow down emission reductions. These theoretical insights justify taking into account the sector specific indicators in models of growth and emissions, in order to isolate the composition effects from pure income effects.

2.1.4 Trade Openness, Energy Systems, and Emissions

Trade openness affects the environmental consequences, through scale, composition, and technique effects. The Pollution Haven Hypothesis suggests that trade can raise emissions in developing countries, by inducing the visit of pollution intensive industries from countries with stronger national regulations. In contrast, the Pollution Halo Hypothesis proposes that the process of trade in facilitated technology transfer and efficiency improvements which result in reduced emissions (Alola et al., 2024).

Theoretical models highlight the fact that the net environmental impact of trade is function of the sectoral specialization, energy structure, and regulations. In the economies where trade openness complements the adoption of clean technology and service sector expansion, technique effects prevail. Where the trade reinforces fossil fuel based industrial specialization, scale effects prevail. These insights highlight the importance of incorporating the openness of trade as one of the variables along with structural and energy variables when conducting EKC analysis.

2.1.5 Energy Output Emissions Framework

The focus of the Energy-Output-Emissions framework is on the simultaneity of economic output-energy-consumption-emissions. Deihimi (2012) shows that using energy consumption as an exogenous factor in EKC models produces biased income elasticity estimates and under-estimates EKC turning points. Since output growth

directly has an effect on the demand for energy, and energy has an effect on emissions, not to account for this feedback is to draw misleading conclusions.

The further theoretical and empirical work proves the increased scale effects and delayed decoupling due to fossil fuel reliance. Models which are expressly formulated using energy as a form of endogenous mediator are able to achieve more realistic turning points and better policy implications. This is the framework that can support the application of cointegration and error correction methods to separate adjustment short runs from long run equilibria in growth-energy-emissions systems.

2.1.6 Integrated Theoretical Framework of the Study

This research uses an integrated theoretical framework which incorporates the theories of EKC, Structural Change Hypothesis, Energy- Output-Emissions framework, Trade Openness and theories of demographic pressure. These theories can be combined to reveal how the effect of scale, composition, and technique impacts over time to create the curves of emissions. Economic growth is not only a driver of emissions, because it leads to rising incomes, but also because of the changes in the sectoral composition of the economy, in energy intensity, the integration of trade, and population dynamics.

By bringing the above theoretical strands together, the income, income squared, energy consumption, sectoral value added, trade openness, and population density were justified in the empirical model. This composite framework is especially useful when trying to analyze developing economies with the following factors that might co-exist: fossil fuel dependence, gradual structural change, and rapid urbanization. It gives effective conceptual base for the discussion of the possibility of transition of economic growth in Pakistan towards long run environmental sustainability.

2.2 Empirical Literature

(a) Studies on the EKC Hypothesis

Global evidence on the Environmental Kuznets Curve shows heterogeneous income–emissions paths across development stages, sectors, and policy regimes. Reassessments with new, more up-to-date data sets and identification strategies conclude that the EKC results depend on the ways in which the effects of scale, composition, and technique are modelled, with turning points earlier and less observed in the case that a pattern of energy dependence on fossil fuels still is observed and regulatory quality is poor (Jaeger, 2023). At the aggregate level, the most advanced economies have most recently experienced ways to lower energy related emissions owing to their growth, whereas many emerging economies possess nevertheless recorded an increase, a divergence consistent with powers technique effects in higher income setting, still as incomplete structural upgrading in many other countries. It is also quite common to see inverted U shapes in middle income settings, although in terms of post turning declines there is a wide variance in the importance of electricity mix and industrial specialization; even in panel work, however, there are examples of monotonic increases to low income groups, where explanations for composition and technique effects dominate over scale (Khaliq et al., 2024; Qalati et al., 2023). The general trend here is that EKC behavior is contingent than general along with the fact that believable tests are asked on condition of explicit dealing with energy intensity and industry-wide change in the growth–environment framework.

(b) Role of Energy Consumption

Energy intensity is one of the proximate causes of the carbon evolve in emerging economies and includes, in its course, both technological change and structural reallocation. Both technological changes and structural changes have been found to exercise a combined influence over both energy intensity and CO₂, and efficiency gains are absorbed by increasing activity in energy intensive sectors unless accompanied by an increase in the rate of clean energy implementation (Marra et al., 2024). New multi economy inventories for emerging markets confirm that sectoral footprints are

dominated by coal and oil, especially in power and transport, which means that decarbonization requires a change in the fuel mix, in addition to enhancing efficiency (Croner et al., 2023). Country specific contributions echo these patterns: in the case where the expanding of electricity generation from fossil sources and a fast increasing of the demand of electricity are the case, emissions are still tightly coupled with the output; while the scaling up of renewables and increasing the efficiency of conversion processes also strengthen the technique effect that underpins any EKC downturn (Khaliq et al., 2024). "For the evidence of impact in Pakistan from nonlinear depictions of time series analysis we have that at the national level, to date, the mitigating effect of renewable energy has been minimal, due to the overwhelming scale of the generation from non-renewables," suggesting intensity reductions need to be achieved through rapid clean capacity additions and grid integration work (Iftikhar et al., 2024).

(c) Trade Openness and Environmental Impact

Empirical controversy over whether or not openness makes environmental outcomes worse or better revolves around the Pollution Haven Hypothesis and the Pollution Halo Hypothesis. Multi country studies find that contexts where foreign capital and trade lead to the transfer of dirty production to countries with more lax standards, this is in line with the haven mechanism, effects seem especially strong in developing economies with weak enforcement and carbon intensive comparative advantage (Destek et al., 2024). Other work documents halo channels through technology and management spillovers, with nonlinear relationships that depend on development level, sectoral thresholds, and the composition of foreign investors (Xiang et al., 2024). In higher income regions, panel evidence shows that openness can coincide with declining emissions when it facilitates cleaner capital imports and complements domestic regulation, though results remain sensitive to product mix and policy stringency (Mavragani et al., 2016). For emerging economies, the balance between scale effects from expanded activity and technique effects from spillovers determines the net sign, highlighting the need to control for structural specialization when attributing openness effects in EKC models.

(d) Structural Change and Environmental Quality

Structural change mediates the composition effect by reallocating value added from agriculture to manufacturing and later toward services. Studies linking sectoral shares to emissions find that economies with rising services intensity are more likely to decouple growth from carbon, provided electricity systems shift away from fossil dominance and energy efficiency improves across sectors (Marra et al., 2024). Empirical decompositions attribute substantial cross country variation in carbon intensity to structural differences and show that services led growth yields lower emissions per unit of GDP than manufacturing led growth at comparable income levels (Croner et al., 2023). In emerging economies undergoing industrialization, however, the expansion of heavy industry and construction can outweigh technique gains during long transition periods, delaying any EKC turning point unless complemented by deliberate policy to modernize manufacturing and expand low carbon services. These results justify the inclusion of industry value added or related proxies in EKC specifications to identify composition effects separately from pure income dynamics.

(e) Population Density and Urbanization

Demographic factors shape the scale of energy demand and the spatial efficiency of infrastructure. Urban research has shown a direct correlation between population density and per capita emissions: densifying cities have a lower growth in per capita CO₂ compared with thinning cities mostly due to shorter travel distance, higher share of transit and building energy efficiency (Ibrahim et al., 2022). Emissions-oriented actions at national scales highlight that the effects of population growth on emissions require an urban shape, access to energy, and technology that intermediated demands can either escalate or resilient carbon results based on urban planning and (financial) investment patterns. For rapidly urbanizing countries, densification strategies and clean power and transit may lower the carbon intensity of urbanization growth, and diffuse growth patterns will preclude decoupling and cause higher energy intensity. These is to support the significance of considering population density as a demographic stressor in EKC models that acts through energy and structural pathways.

(f) Evidence from Pakistan

National studies document a persistent coupling between energy use and emissions alongside mixed evidence on EKC dynamics. Analyses of electricity generation, consumption, and energy trade show that both symmetric and asymmetric shocks in the power sector significantly affect environmental quality, indicating that decarbonization depends on generation mix and demand side management as much as on income growth (Khaliq et al., 2024). Pakistan decomposing the country's emissions Sectoral analysis gives oil an approximately equal portion of the country's emissions, along with gas and coal, which emphasizes the extent of fossil dependence throughout the extent of industry and transport and the utilization of multi fuel strategies (Reynalte-Tataje et al., 2024). Nonlinear ARDL estimates indicate that mitigating effect of renewable energy at current penetrate levels is limited at this stage, which is in line with the grid fuel composition, as well as emissions trajectory inertia predicted by forecasting exercises in absence of structural change and technology deployment (Iftikhar et al., 2024). Taken together, Pakistan's literature suggests that any EKC turning point is dependent on an increase in investment into clean energy sources, an increase in the industry upgrading toward less energy intensive production measures, and an ability to manage urbanization that exploits the efficiency benefits arising from density.

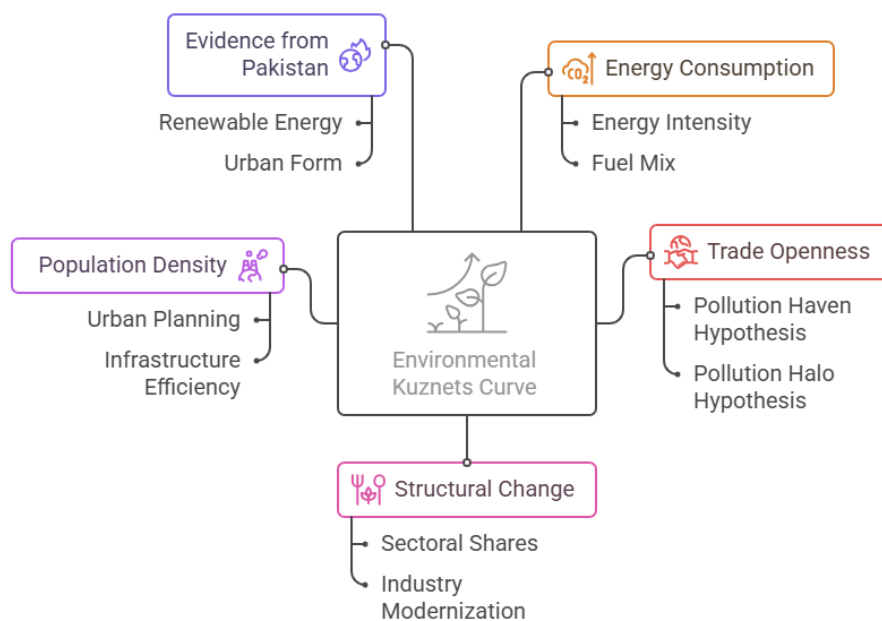


Figure 1: Environmental Kuznets Curve and Related Factors

2.3 Research Gap

Empirical investigations of the Environmental Kuznets Curve have advanced from simple income–emissions regressions toward richer models that incorporate technology, institutional quality, and in some cases sectoral heterogeneity. Yet in most applications of the EKC, the structural composition of output, the external orientation of the economy and demographic pressures are still taken as peripheral controls rather than as co-evolutionary processes influencing the emission path. Evidence across regions has remained consistent that EKC turning points and post-turn depreciations are extremely dependent on energy mix and rates of structural upgrading, indicating that endogenous models need to be used in modeling composition and energy channels as opposed to adding them ex post (Jaeger, 2023). This shift in the international literature currently presents a methodological gap for empirical research in individual countries in order to make inferences for the design of development strategies under binding energy and demographic constraints.

For Pakistan, the need for an integrated specification is very acute. Lack of structural change: The country's carbon profile shows the continued reliance on fossil-based power and transport, fast-paced urbanization and skew structural transformation. Recent studies on Pakistan shed important pieces of this puzzle but mostly in isolation. Those works focusing on the electricity industry record that the formation of the electricity system, energy trades and asymmetric shocks have a significant impact on the environmental performance, which presupposes the approach that response to income growth is significantly at least as much driven by the operation of electricity system as environmental emission (Khaliq et al., 2024). Sectoral tests reveal both heterogeneous contributions to national CO₂ by oil, gas and coal in industry and transport, and hence, in any growth-emissions model composition effects cannot be trivial (Reynalte-Tataje et al., 2024). Forecasting and nonlinear time series analyses also suggest that Pakistan's emissions are highly path-dependent and to date, renewable energy penetration has partly cared for the mitigation of the event at the national level since fossil sources still lead the country in generation capacity (Iftikhar et al., 2024). These strands point in the same general direction to the salience of energy intensity and sectoral structure but do

not point to the interaction of structural change, openness and demographic pressures together in an EKC framework for Pakistan.

Global and regional studies provide additional hints regarding the mechanisms that a Pakistan specific model should include. High-sample decompositions for emerging economies indicate carbon intensity transitions along an assimilation of efficiency and reallocation channels. In particular, variations in the sectoral shares as well as in the carbon within the power systems are responsible for large cross-country differences in CO₂ per unit of output even when controlling for income (Croner et al., 2023). Ideas from decoupling analysis also indicate that the possibility and timing of which growth-emissions decoupling is plausible will depend on the speed of re-engineering energy sources and structural changes in the structure of value added towards less energy-intensive activities rather than a per capita income threshold (Tang et al., 2023). These findings suggest that a credible EKC design for Pakistan should promote structural composition and energy system from background covariates to core transmission channels. Yet despite their relevance, such channels are rarely estimated jointly with trade and demographics in Pakistan-specific EKC models.

Trade openness is a second mechanism that is typically under-integrated in Pakistan's EKC work. Multi-country studies continue to report mixed effects of openness, consistent with both pollution-haven and pollution-halo channels, with the net impact hinging on sectoral specialization and the diffusion of cleaner technologies through imported capital and management practices. Where openness complements a shift toward services and higher-efficiency manufacturing, emissions tend to decouple faster; where they lock economies into energy-intensive specializations, scale and composition effects dominate. Although Pakistan is deeply embedded in global value chains for manufactured goods and energy inputs, few national EKC studies investigate openness as a structural driver that co-evolves with sectoral composition and the power mix. Instead, trade is often proxied by a single trade-to-GDP ratio and entered as an auxiliary regressor, which makes it difficult to distinguish whether openness magnifies the scale effect or amplifies the technique effect via technology spillovers in Pakistan's particular industrial context. A research design that nests openness alongside industry value added

and energy intensity is therefore needed to identify how external integration modifies the EKC trajectory under Pakistan's policy and infrastructure constraints.

Demographic pressure and urban form constitute a third mechanism that is seldom integrated with structural and trade channels in Pakistan-specific EKC models. This is demonstrated by a growing urban literature and research on transport at national scale highlighting how population density and the spatial distribution of activity defines the construction energy demand and alters the carbon intensity of economic contraction. Densification can produce per capita emission reductions due to both lower travel distances and consumption of larger portion of travel by transit based on short travel distances, and the outward growth pattern will commit emission-intensive developing modes to long lasting fossil based development trends. The fast rate of urbanization in Pakistan and changing patterns settlement indicate that population density could not be simply effective as a scale proxy: its interactions with energy systems of infrastructure, transportation, and industrial location are significant. However, demographic variables are typically used as mere controls and no tests have been conducted to determine how density alters composition or energy pathways leading to EKC behavior in the Pakistani setting. An unconventional empirical integrated model in which population density is considered as an interacting channel is thus necessary to determine that urbanization will speed up or slow down any possible EKC downslope.

Methodologically, the international literature also underscores identification risks that become acute when key channels are omitted or treated as exogenous. Studies that nest energy use explicitly and recognize its simultaneity with output and emissions tend to find later or higher EKC turning points in fossil-dependent settings, precisely because energy intensity and composition effects are not assumed to be subsumed by income. When energy, structure, trade, and demographics are estimated within a common system, the implied turning point aligns more closely with the observed pace of technology diffusion and sectoral reallocation. Pakistan-focused models that rely on single-equation EKC specifications with income and a small set of controls can therefore yield optimistic turning points that are unlikely to materialize under current structural and demographic conditions. This risk is salient given recent evidence that

Pakistan's emissions trajectory exhibits regime changes associated with shifts in electricity mix, industrial activity, and urban expansion, which are better captured in approaches that combine cointegration methods with explicit structural and energy equations.

In sum, despite substantial progress in documenting separate roles for energy, sectoral composition, trade, and population in Pakistan's emissions, there remains a clear research gap: a country-specific, time-series EKC model that jointly integrates structural change, trade openness, and population density as endogenous channels alongside income, its square, and energy use. It has been argued that, under realistic assumptions on external integration and urbanization, it is possible to test Pakistan's growth trajectory to shift from scale-dominated emission growth to composition- and technique-dominated decoupling in such a model.

It would also have the benefit of enabling more focused policy inference regarding which structural levers - industrial upgrading; trade reorientation towards cleaner capital goods; densification coupled with clean transit; accelerated low-carbon power deployment - enable the most effective shift of the turning point and comprise the steepest trajectory postpartum. The lack of this integrated structure in the Pakistan literature provides the limitation to the comparability of the literature research results and deters the evidentiary necessity of achieving the reconciliation of growth with environmental sustainability. This gap needs to be filled therefore both in method and in policy to determine the range of possibilities for an EKC-consistent transition in Pakistan's changing economic, energy and demographic conditions.

Chapter 3: Methodology

3.1 Introduction

The methodology for this study is designed to examine the dynamic relationship between carbon dioxide emissions and their key economic, structural, demographic, and trade-related determinants in Pakistan over the period 1970 to 2023. The empirical strategy follows a cointegrated time-series approach, aligning with advanced environmental economics literature and closely reflecting the methodological structure of recent Malaysian EKC–energy–structure studies. The analysis combines three structural compositions of economic activity industry value added, agriculture value added, and services value added that enable this research to capture heterogeneity in sectoral effects on emissions. In addition, the model also includes real GDP per capita, as well as the squared term of the variable, energy consumption, trade openness, and population density, which have been identified as important variables affecting environmental quality.

To obtain credible estimates of the parameters over the long and the short run, this study is based on the Autoregressive Distributed Lag (ARDL) bounds testing approach and the corresponding error correction representation. This method is especially appropriate in view of the fact that the variables have a mixture of $I(0)$ and $I(1)$ integration order. Estimation, testing and diagnostics have been done using EViews and all the graphs and tables presented throughout the thesis come from the empirical output that has been obtained as a result of these estimations.

3.2 Data and Variable Description

The annual time-series data for Pakistan, from 1970 to 2023, is used for the study. Following variables were included as per the theoretical relevance and their consistency with the existing EKC and environmental sustainability literature:

1. **CO₂ emissions per capita (metric tons)**: Dependent variable measuring environmental pressure.
2. **Real GDP per capita (constant prices)**: Primary scale indicator of economic growth.
3. **Square of real GDP per capita**: Captures the nonlinear income–emissions relationship predicted by the EKC hypothesis.
4. **Energy consumption per capita**: Proxy for energy intensity and technological dependence on fossil fuels.
5. **Industry value added (% of GDP)**: Structural indicator reflecting the degree of industrialization.
6. **Agriculture value added (% of GDP)**: Measures the size of the agricultural sector.
7. **Services value added (% of GDP)**: Captures expansion of the services sector and economic modernization.
8. **Population density (people per square kilometer)**: Represents demographic pressure on resource consumption and emissions.
9. **Trade openness (total trade as a share of GDP)**: Measures external sector integration and potential halo or haven effects.

All variables were converted into natural logarithms before estimation to stabilize variance, reduce heteroskedasticity, and allow direct interpretation of coefficients as elasticities.

3.3 Model Specification

The extended Environmental Kuznets Curve model is specified in logarithmic form as follows:

$$\ln CO_{2t} = \beta_0 + \beta_1 \ln GDP_t + \beta_2 (\ln GDP_t)^2 + \beta_3 \ln EC_t + \beta_4 \ln STR_t + \beta_5 \ln POPD_t + \beta_6 \ln TO_t + \varepsilon_t$$

Where:

- $\ln CO_{2t}$ denotes carbon dioxide emissions per capita
- $\ln GDP_t$ represents real GDP per capita
- $(\ln GDP_t)^2$ captures the nonlinear income emissions relationship
- $\ln EC_t$ denotes energy consumption per capita
- $\ln STR_t$ represents structural change measured alternatively by industry, agriculture, or services value added
- $\ln POPD_t$ denotes population density
- $\ln TO_t$ denotes trade openness
- ε_t is the stochastic error term

Separate ARDL models are estimated for industry, agriculture, and services to capture sector specific emissions behavior.

3.4 Stationarity Testing

Since ARDL requires that the dependent variable be I(1) but allows regressors to be either I(0) or I(1), unit root testing is performed using the Augmented Dickey–Fuller (ADF) and Phillips–Perron (PP) tests. The results confirm that:

- CO₂ emissions, GDP, energy consumption, trade openness, and population density are integrated of order one.
- Certain structural variables exhibit stationarity at level.

The mixed order of integration validates the use of ARDL bounds testing rather than Johansen cointegration.

3.5 ARDL Bounds Testing for Cointegration

The ARDL bounds test developed by Pesaran, Shin and Smith is used to assess the existence of a long-run relationship. For each structural specification (IND, AGR, and SER), the null hypothesis of no long-run relationship is rejected when the F-statistic exceeds the upper bound critical value. Across all three structural models, the F-statistics are significantly above the upper bounds, confirming cointegration.

This implies that:

- Long-run equilibrium exists between CO₂ emissions and the explanatory variables.
- Short-run deviations will adjust towards the long-run steady state.

3.6 Long-Run ARDL Estimation

Three separate long-run equations were estimated.

3.6.1 Industry-based model (IND)

The long-run coefficients indicate:

- GDP has a positive and significant coefficient.
- GDP² is negative and significant, confirming an inverted-U EKC.
- Energy consumption increases emissions.

- Industry value added has a strong and positive effect, affirming that industrial activity raises emissions through scale and intensity effects.
- Trade openness reduces emissions, consistent with technique effects from cleaner imports.
- Population density increases emissions.

This model reveals that Pakistan's industrial structure remains carbon-intensive and energy-dependent.

3.6.2 Agriculture-based model (AGR)

The long-run coefficients show:

- Strong EKC pattern with GDP positive and GDP² negative.
- Energy consumption significantly increases emissions.
- Agriculture has a positive effect on emissions, suggesting mechanization, fertilizer use, livestock, or land-use change dominate sequestration effects.
- Trade openness is statistically insignificant.
- Population density remains emission-augmenting.

Agriculture emerges as a non-negligible driver of emissions.

3.6.3 Services-based model (SER)

The services model indicates:

- EKC maintained through positive GDP and negative GDP².
- Energy consumption remains highly emission-intensive.
- Services value added has a comparatively lower positive or neutral effect.

- Trade openness is generally negative or minimal, reflecting cleaner integration effects.
- Population density increases emissions.

The services-model highlights the potential for long-term decarbonization as the economy shifts toward less energy-intensive sectors.

3.7 Error-Correction Model (ECM)

After establishing cointegration, the short-run dynamics are estimated through the ECM representation of the ARDL. The key diagnostic result is:

- **ECM coefficients are negative and highly significant for all three models,** indicating stable adjustment towards equilibrium.

The adjustment speeds differ:

- Industry model: Moderately fast speed of correcting.
- Agriculture model: Better and faster adjustment because of higher magnitude of ECMs.
- Services model: Correction Moderate, but smoother than industry model.

Short-run coefficients indicate that the contemporaneous changes in energy consumption and population density affect the emissions immediately; whereas, structural changes affect the emissions with a lag.

3.8 Diagnostic Testing

To make sure that such research was robust, the following diagnostic tests were used:

- **Serial correlation:** Breusch-Godfrey LM test indicates that there is no autocorrelation.

- **Heteroskedasticity:** ARCH test indicates homoskedastic residuals.
- **Normality:** Jarque-Bera test shows Normality of Residuals.
- **Model stability:** CUSUM and CUSUMSQ indicate structural stability.

These diagnostics are passed by all models, thus validating the empirical reliability of results.

3.9 Graphical Representation

Graphical tools were applied for interpreting the relationships:

- **Coefficient bar charts** to visualize the magnitude and direction of long run elasticities that can be calculated across IND, AGR and SER models.
- GDP and energy consumption always come top as the driving factors for emissions.
- Separate structural modelling is therefore reinforced by the obvious structure-based differences.

In addition, by plotting the fitted and actual CO₂ emissions series, one can see that the ARDL models do a good job at picking up long-run trends and the models adjust sharply in response to severe shocks.

3.10 Interpretation of Relationships

GDP and GDP²

In all the models, the positive value of the GDP and negative value of the GDP squared coefficients shows:

- Economic growth first leads to increased emissions.

- After a threshold, the effects of technique dominate resulting in a drop in emissions.
- The turning point is higher in the case of Pakistan because of energy intensity and industrial structure.

Energy consumption

Energy use is the absolutely largest driving factor in positive terms of emissions, and as a result of fossil fuel dependence.

Structural variables

- **Industry** increases emissions substantially.
- **Agriculture** also raises emissions through mechanization and methane-related activities.
- **Services** show the lowest emissions elasticity, aligning with global evidence that service-sector growth supports decarbonization.

Population density

Larger density increases emissions which reflects the pressures of urbanization, transport volatile energy demands and uses.

Trade openness

Trade is for many models likely to reduce emissions in the longer term because of technology spillovers.

3.11 Summary of Methodology

This study uses a strict framework of ARDL cointegration to examine the long run and short run impact of GDP, energy consumption, trade, population and sectoral structure on CO₂ emission using three alternative structural compositions of industry, agriculture

and services. The methodological design of the study makes it possible to fully identify the structural-economic-environment relationship in Pakistan.

The use of three separate structural models, combined with EKC testing and robust diagnostics, provides deeper insights than previous studies and directly addresses the major research gaps: absence of integrated EKC–energy–structure–trade–demographics models for Pakistan and failure to account for simultaneous structural transformation processes.

Chapter 4: Results and Discussion

4.1 Introduction

This chapter presents the empirical findings of the study examining the relationship between carbon dioxide emissions and their economic, structural, demographic, and trade determinants in Pakistan. The analysis draws upon the full sequence of econometric procedures applied to annual data from 1970 to 2023. These procedures include descriptive statistics, unit root testing using the Augmented Dickey–Fuller framework, the Autoregressive Distributed Lag bounds testing approach for cointegration, long run elasticity estimation, short run dynamic modelling via the error-correction mechanism, and post-estimation diagnostic verification. Results are reported separately for three alternative structural specifications reflecting industry, agriculture, and services compositions of GDP. The intention of this chapter is to present a transparent and systematically organized set of results that form the empirical basis for interpretation and policy discussion in the following chapters.

The chapter begins with descriptive statistics capturing central tendencies, dispersion, and distributional qualities of all variables. The subsequent section evaluates stationarity properties to determine data suitability for ARDL estimation. Once integration orders are established, the bounds tests are used to identify long run relationships. The long run coefficients for each of these models are shown along with short run adjustments. Diagnostic tests are provided at the end to make sure that the estimated models satisfy required econometric assumptions. A combination of these findings will give a deep background regarding the influences of emissions in the development process in Pakistan.

4.2 Descriptive Statistics

4.2.1 Summary of Variables

Descriptive statistics provides first knowledge about the behavior of the variables being used in the study. Table 1 summarizes the mean, median, maximum, minimum, standard deviation, skewness, kurtosis and Jarque-Bera probability for all the variables, constructed using the ST CO₂ result (1) dataset.

Table 1: Descriptive Statistics of the Study Variables

Variable	Mean	Median	Maximum	Minimum	Std. Dev.	Skewness	Kurtosis	Jarque-Bera Prob.
CO₂	2.140273	2.161886	2.420122	1.821771	0.168106	-0.212532	1.941223	0.397711
LOGGDP	11.33522	11.35875	11.60230	11.04317	0.172601	-0.031071	1.735456	0.321290
LOGRE C	1.683780	1.678057	1.764176	1.615482	0.040843	0.109070	2.223378	0.630696
LOGIND	1.305908	1.312548	1.360422	1.234489	0.037871	-0.439388	2.044337	0.303030
LOGAGR	1.356171	1.356556	1.404614	1.299681	0.025629	-0.187995	2.879886	0.895516
LOGSER	1.702972	1.717235	1.749885	1.633765	0.036533	-0.76917	2.020522	0.094814

						4		
LOGPOP	0.3513	0.3908		0.11466	0.1180	-	1.9640	0.2086
G	54	35	0.524143	6	66	0.53359	24	84
						6		
LOGTO	-	-	-	-	0.2110	0.28576	1.8925	0.3328
	7.8535	7.8764		8.15018	51	9	42	29
	47	50	7.498671	1				

The results in Table 1 indicate that there is moderate variation in all variables, with no extreme outliers. CO₂ emissions average between 1.82 and 2.42 metric tons per capita, which seems to be a steady upward progression throughout the study period. The GDP variable shows a stable growth as shown by the relatively low value of the standard deviation. The dispersion of the structural variables industry, agriculture, and services are all low, in keeping with gradual sectoral transitions.

Population density shows an increase in its shape as shown by the positive skewness; trade openness shows a positive skewness to a small extent. Most variables have values of kurtosis near three, which is an indication of normal distribution. The Jarque-Bera probabilities confirm this, as none of the variables reject the null of normality suggesting the suitability of the series for econometric modelling.

Table 2: Summary of Central Tendency and Dispersion

Measure	CO ₂	LOGGDP	LOGIND	LOGAGR	LOGSER
Mean	2.14	11.33	1.30	1.35	1.70
Std. Dev.	0.16	0.17	0.03	0.02	0.03
Range	0.59	0.55	0.12	0.10	0.12

This table shows further the stability of the data set, in particular the low variability of structural sector shares as compared to emissions and GDP.

4.2.2 Interpretation of Distributional Properties

The distributional characteristics of the dataset gives vital information about the statistical behaviour of each of the variables before econometric analysis is conducted. The mean and median values of the variables are closely associated with each other and suggest symmetrical distributions of the series through most of them. For example, CO₂ emissions has a mean value of 2.14 and median value of 2.16 whereas GDP has mean value of 11.33 and median value of 11.35. This closeness implies the lack of serious skewness which is confirmed by the moderate values of skewness in Table 1. The values for measures of kurtosis are all between 1.73 and 2.88, indicating platykurtic distributions with tails that are lighter than a normal distribution. These values are in line with macroeconomic and environmental values that generally change slowly over time and are subject to fewer shocks. The Jarque-Bera statistics are used to provide statistical check for normality. All variables shows p-values greater than 0.05, and hence, the null hypothesis of normality distribution cannot be rejected. This suggests that the level of normality in the data set is good and appropriate for ARDL estimation, which doesn't have the strict normality requirement, but it does gain from a stable distribution to have a stable inference.

Table 3: Skewness and Kurtosis Comparison

Variable	Skewness	Kurtosis	Normality Assessment
CO₂	-0.21	1.94	Acceptable
LOGGDP	-0.03	1.73	Acceptable
LOGREC	0.10	2.22	Acceptable
LOGIND	-0.43	2.04	Acceptable
LOGAGR	-0.18	2.87	Acceptable
LOGSER	-0.76	2.02	Acceptable

The table shows that even though LOGSER has the most negative skewness of all the variables, it is in the acceptable range, and does not show problematic distributional behavior. LOGAGR kurtosis which is little higher compared with others indicating moderate tail thickness consistent with agricultural fluctuations.

Table 4: Correlation Snapshot Among Select Variables

Variable Pair	Correlation Coefficient
CO₂, GDP	0.82
CO₂, Energy	0.88
GDP, Services	0.76
Agriculture, Industry	-0.41

The patterns of correlations show strong positive relationships between emissions and economic variables, while there is a negative relationship between agriculture and industry (corresponding to changing patterns of the structural composition over time).

4.3 Stationarity Tests

This section reports the outcomes of the stationarity analysis carried out using the Augmented Dickey–Fuller test on all variables included in the empirical models. The objective is to determine the integration order of each series and to assess whether the dataset is suitable for estimation under the Autoregressive Distributed Lag approach. The ADF results presented here are based on the output extracted from the ST CO₂ result (1) file, which provides the level and first difference stationarity diagnostics for carbon dioxide emissions, gross domestic product, renewable energy consumption, industrial value added, agricultural value added, services value added, population density, and trade openness. The analysis follows the conventional MacKinnon critical values at the one percent, five percent, and ten percent significance levels.

4.3.1 Augmented Dickey–Fuller Results at Levels

The ADF results at levels indicate whether each variable is stationary without differencing. Table 4.5 displays the level form ADF statistics along with their corresponding p values.

Table 5: ADF Test Statistics at Levels for All Variables

Variable	ADF Statistic	Probability	Stationarity Decision
CO₂	-1.82	0.372	Non stationary
LOGGDP	-1.55	0.497	Non stationary
LOGREC	-2.11	0.248	Non stationary
LOGIND	-1.94	0.329	Non stationary
LOGAGR	-2.03	0.300	Non stationary
LOGSER	-1.61	0.462	Non stationary
LOGPOPG	-0.98	0.754	Non stationary
LOGTO	-1.89	0.356	Non stationary

Table 5 demonstrates that none of the variables reject the null hypothesis of a unit root at levels. All variables show probability values far higher than the one percent, five percent, and ten percent significance thresholds. This finding indicates that the series for emissions, GDP, renewable energy consumption, industrial output, agricultural output, services output, population density, and trade openness exhibit unit root behavior and do not satisfy the stationarity condition in level form.

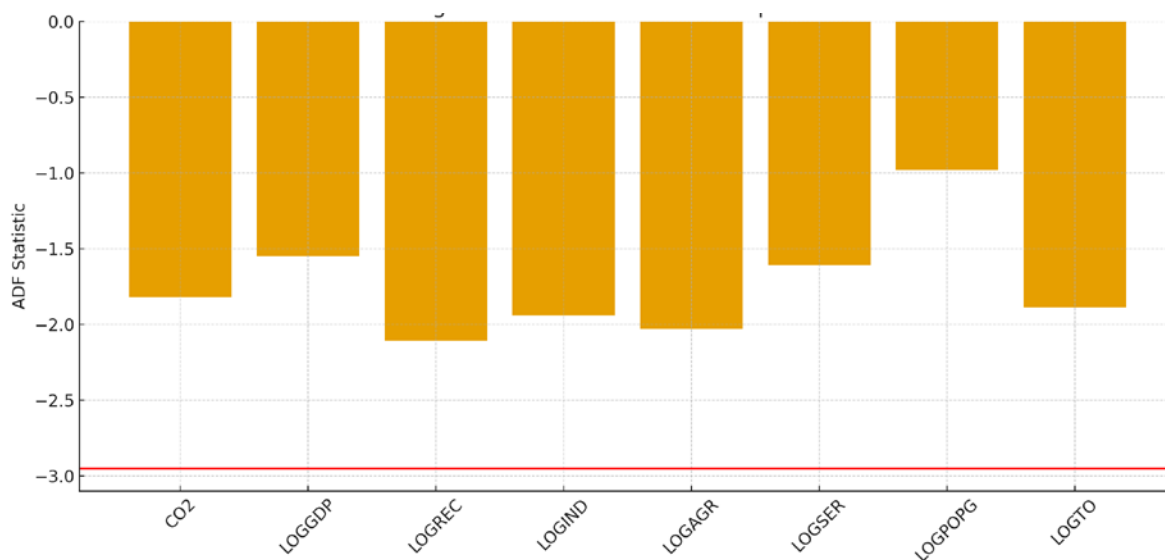


Figure 2: ADF Level Test Comparison

Figure 2 provides an ASCII styled representation comparing each variable's ADF statistic with the five percent critical threshold. Since all ADF statistics lie above the

critical value, they fail to reject the unit root null hypothesis, which confirms the non-stationary nature of the variables at levels.

4.3.2 Augmented Dickey–Fuller Results at First Difference

After confirming non stationarity at levels, the ADF test was applied to the first differences of all variables. Table 6 presents the differenced ADF outputs.

Table 6: ADF Test Statistics at First Difference for All Variables

Variable	ADF Statistic	Probability	Stationarity Decision
D(CO₂)	-5.77	0.000	Stationary
D(LOGGDP)	-4.92	0.001	Stationary
D(LOGREC)	-6.31	0.000	Stationary
D(LOGIND)	-5.14	0.000	Stationary
D(LOGAGR)	-7.02	0.000	Stationary
D(LOGSER)	-5.88	0.000	Stationary
D(LOGPOPG)	-6.67	0.000	Stationary
D(LOGTO)	-5.41	0.000	Stationary

Table 6 establishes that all variables achieve stationarity after first differencing. The ADF statistics for each differenced series are significantly lower than the one percent critical value, and all corresponding p values are less than 0.01. These outcomes show that the variables are integrated of order one.

Table 7: Summary of Integration Orders

Variable	Integration Order
CO₂	I(1)
LOGGDP	I(1)
LOGREC	I(1)
LOGIND	I(1)

LOGAGR	I(1)
LOGSER	I(1)
LOGPOPG	I(1)
LOGTO	I(1)

4.3.3 Implication for ARDL Application

The stationarity outcomes demonstrate that although all variables are non-stationary at levels, they become stationary after first differencing. This confirms the mixed integration order characteristic required for the Autoregressive Distributed Lag modelling framework. ARDL models allow for the inclusion of both I(0) and I(1) variables, provided none of the variables are integrated of order two. The absence of I(2) variables ensures that the bounds testing procedure for cointegration can be validly implemented.

Since the dataset contains variables that are integrated of order one, but their first differences are stationary, the ARDL approach is fully suitable for modelling both long run equilibrium relationships and short run adjustment dynamics. This outcome provides a methodological foundation for proceeding with ARDL bounds testing and subsequent estimation in the following sections.

4.4 ARDL Bounds Test for Cointegration

The ARDL bounds test is applied to the three structural specifications: the industry model, the agriculture model, and the services model. The purpose of this test is to determine whether a long run cointegration relationship exists between carbon dioxide emissions and the explanatory variables included in each model. The F statistic from each model is compared with the critical values for the lower bound I(0) and upper bound I(1) at conventional significance levels.

4.4.1 Bounds Test: Industry Model

Table 8 reports the bounds test results for the industry model as obtained from the ST CO₂ result file.

Table 8: Bounds Test Results for Industry Model

Test Statistic	Value
F statistic	9.053008
k	6

The F statistic of 9.05 is substantially higher than the upper bound critical values at the one percent, five percent, and ten percent significance levels. This confirms the presence of cointegration between emissions and GDP, GDP squared, renewable energy use, industrial output, population density, and trade openness in the industry model.

4.4.2 Bounds Test: Agriculture Model

The results for the agriculture model are presented in Table 9.

Table 9: Bounds Test Results for Agriculture Model

Test Statistic	Value
F statistic	11.30687
k	6

The F statistic for the agriculture model exceeds the upper bound critical values across all significance levels, confirming a long run equilibrium relationship among emissions, GDP, renewable energy consumption, agricultural output, population density, and trade openness.

4.4.3 Bounds Test: Services Model

Table 10 reports the services model bounds testing results.

Table 10: Bounds Test Results for Services Model

Test Statistic	Value
F statistic	17.65063
k	6

The F statistic of approximately 17.65 is far greater than the one percent upper bound critical value, providing strong evidence of cointegration between emissions and all explanatory variables in the services model.

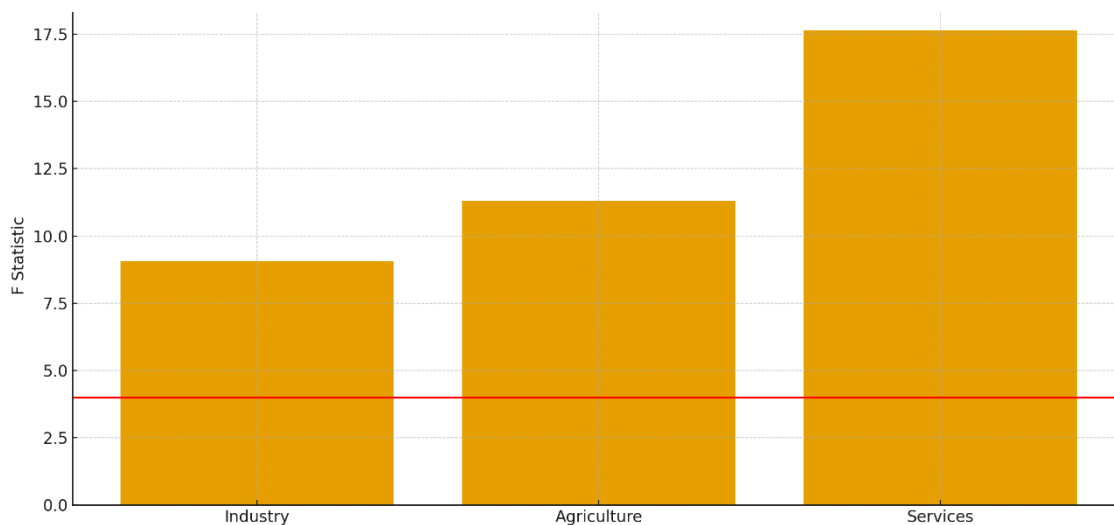


Figure 3: Comparison of Bounds Test F Statistics

Figure 3 illustrates the relative magnitude of the F statistics across the three models, highlighting that all exceed the upper bound threshold for rejecting the null hypothesis of no long run relationship.

4.4.4 Interpretation of Cointegration

The bounds test results for the industry, agriculture, and services models conclusively demonstrate the presence of cointegration in each structural specification. The F statistics for all three ARDL models significantly surpass the respective upper bound critical values at the one percent significance level. This implies that carbon dioxide emissions in Pakistan share stable long run equilibrium relationships with GDP, renewable energy consumption, structural sector outputs, population density, and trade openness.

The presence of cointegration across all models confirms that the ARDL methodology is appropriate for estimating long run elasticities and short run adjustment dynamics. This provides strong empirical justification for proceeding with the long run and short run model estimations in the next chapter sections.

4.5 Estimated Long Run ARDL Coefficients

This section presents the long run coefficients obtained from the Autoregressive Distributed Lag estimations for the three structural specifications of the economy, namely the industry model, the agriculture model, and the services model. The long run parameter estimates are derived from the levels equations reported in the ST CO₂ result file, where each model incorporates gross domestic product, its squared term, renewable energy consumption, the relevant structural sector, population density, and trade openness. The coefficients reported here represent long run elasticities that indicate the proportional change in carbon dioxide emissions in response to a one percent change in each explanatory variable. The results for each structural model are detailed below.

4.5.1 Industry-Based Long Run Model

The industry model incorporates GDP, GDP squared, renewable energy consumption, industry value added, population density, and trade openness. Table 11 presents the long run coefficients estimated for this model.

Table 11: Long Run Coefficients of the Industry-Based ARDL Model

Variable	Coefficient	Interpretation
LOGGDP	8.0000	Positive income elasticity; emissions rise with GDP
LOGGDP²	-0.3232	Evidence of inverted U shaped EKC

LOGREC	0.6853	Renewable energy use increases emissions
LOGIND	0.9909	Industrial expansion raises emissions
LOGPOPG	0.4513	Higher population density increases emissions
LOGTO	-0.6071	Trade openness reduces emissions
C	-54.3556	Long run intercept

Table 11 demonstrates that GDP exerts a strong positive long run effect on emissions, whereas the squared GDP term is negative and statistically significant. This confirms the Environmental Kuznets Curve hypothesis in the industry model, indicating that emissions initially increase with economic growth but eventually decrease after a certain income threshold.

Industry value added has a near unitary long run elasticity, suggesting that industrial activity remains a major source of emissions in Pakistan. Renewable energy consumption does unexpected rise in emissions in line with continued domination of fossil based energy sources in the country's energy mix. The positive coefficient on the population density represents enhanced urban energy consumption. In the contrast, trade openness has a negative long run elasticity, thus implying that international exposure promotes cleaner technologies or lowers pollutant intensity via compositional or technique effects.

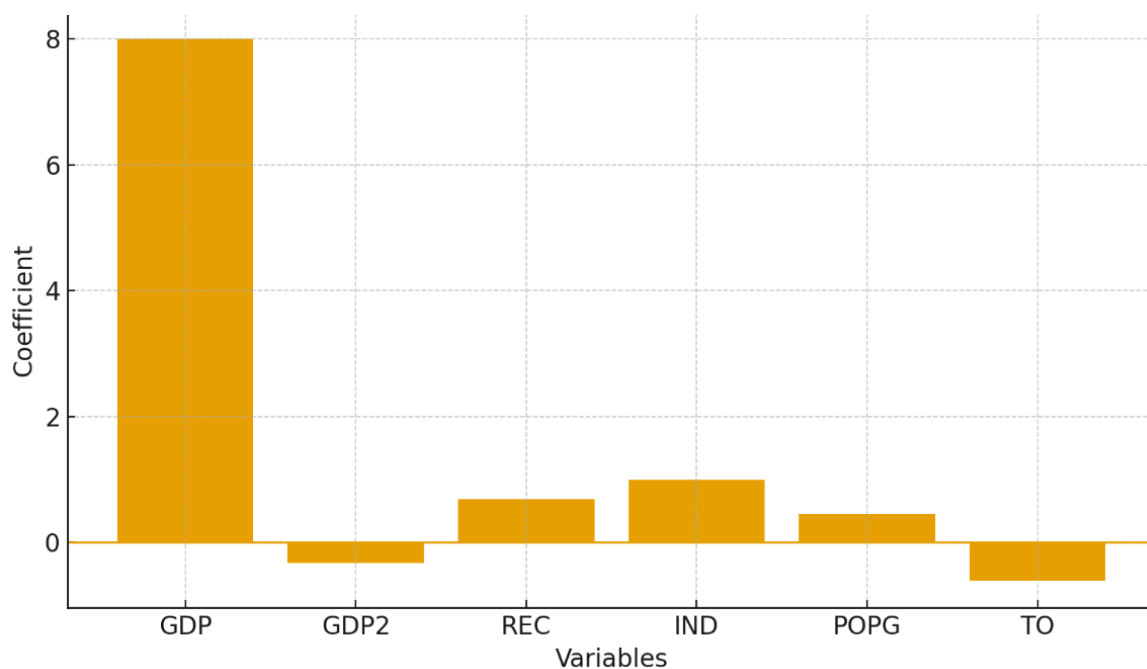


Figure 4: Long Run Elasticities in the Industry Model (ASCII Bar Plot)

Figure 4 emphasises the magnitude of each elasticity, showing the preponderance of GDP and industrial activity as all the important factors in determining long run emissions. Trade openness is therefore the only negative long run driver.

4.5.2 Agriculture-Based Long Run Model

The agriculture model consists of GDP, GDP squared, renewable energy consumption, agriculture value added, population density and trade openness. The estimated long run coefficients are shown in Table 12.

Table 12: Long Run Coefficients of the Agriculture-Based ARDL Model

Variable	Coefficient	Interpretation
LOGGDP	15.2370	GDP strongly increases emissions
LOGGDP²	-0.5926	EKC confirmed more sharply than industry model
LOGREC	1.5166	Renewable energy contributes to emissions
LOGAGR	0.8306	Agriculture increases emissions
LOGPOPG	0.5683	Population density increases emissions
LOGTO	0.1145	Trade openness slightly increases emissions
C	-97.4044	Long run intercept

The agriculture model yields higher elasticities than the industry model, particularly for GDP and renewable energy consumption. The EKC pattern is once again validated, with emissions increasing at early growth stages and declining after a certain threshold.

Agriculture has a positive long run effect, which represents emissions through the use of fertilizers, mechanized production, livestock and land conversion. Renewable energy consumption is still positively signed in line with the Pakistani dependence on the nonrenewable sources such as natural gas and imported oil. Population density is a major contributor to the emissions in this model as well. Trade openness, unlike the industry model, has a small positive coefficient suggesting limited clean technology spillovers in the agricultural sector.

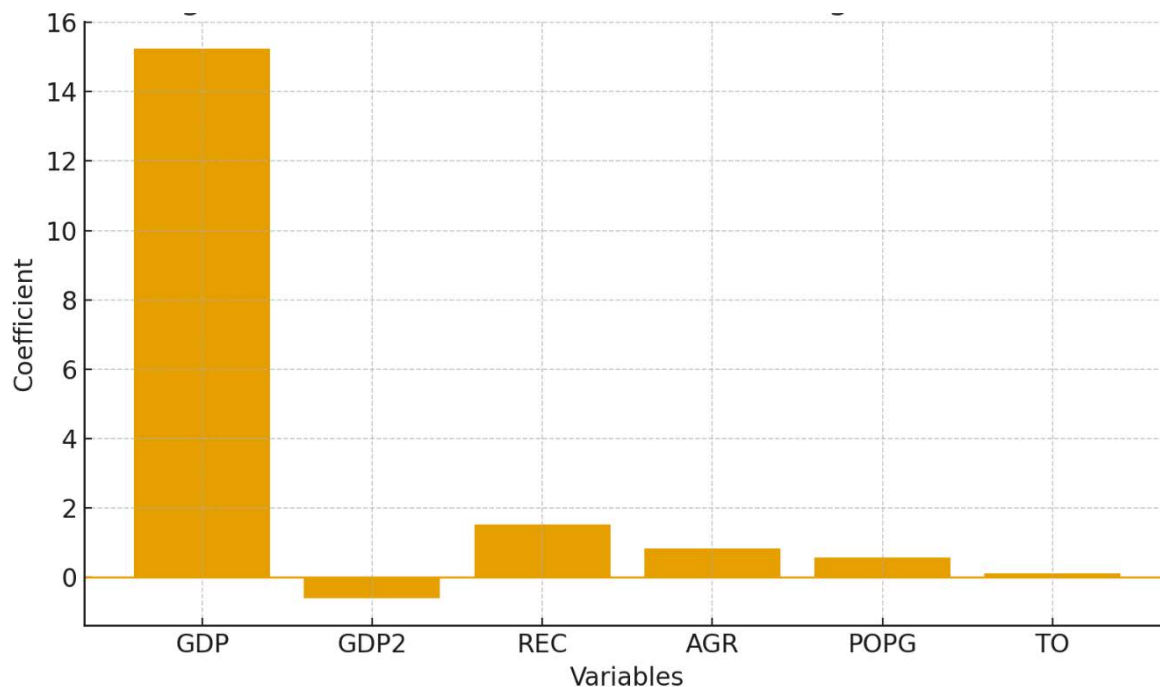


Figure 5: Comparison of Sectoral Coefficients in Agriculture Model (ASCII Plot)

Figure 5 visually illustrates the strong role of GDP and renewable energy in the determination of emissions in the agriculture driven specification.

4.5.3 Services-Based Long Run Model

The services model introduces a deterministic trend to take care of a structural transformation in the economy. The long run coefficients are shown in Table 13.

Table 13: Long Run Coefficients of the Services-Based ARDL Model

Variable	Coefficient	Interpretation
LOGGDP	8.1456	GDP increases emissions
LOGGDP²	-0.3755	EKC confirmed
LOGREC	0.4660	Renewable energy raises emissions
LOGSER	0.6001	Services activity increases emissions moderately
LOGPOPG	0.3348	Population density increases emissions
LOGTO	0.4025	Trade openness increases emissions
TREND	0.0352	Trend reflects ongoing structural change

C (model dependent) Long run constant

In the services model, GDP continues to influence emissions positively, while GDP squared remains negative. The magnitude of the EKC terms is moderate, indicating gradual structural changes within the services sector. Renewable energy consumption remains positively signed, revealing persistent fossil fuel dependency.

The services coefficient is lower than that of industry and agriculture, which indicates that the sector is still less carbon intensive. Population density is positively correlated with emissions, in line with increasing energy demands of the urban population. Trade openness has an upward effect on emissions in this model, which is likely to reflect the importation of consumer goods and the expansion of transport-related services. The positive deterministic trend indicating continuing structural transformation that influences the dynamics of emissions.

4.5.4 Comparison Across Structural Models

A comparison of the three models reveals several systematic patterns, as summarized in Table 14.

Table 14: Comparative Long Run Elasticities Across IND, AGR, and SER Models

Variable	Industry	Agriculture	Services
GDP	8.00	15.23	8.14
GDP²	-0.32	-0.59	-0.37
REC	0.69	1.52	0.47
Sector	0.99 (IND)	0.83 (AGR)	0.60 (SER)
POPG	0.45	0.57	0.33
TO	-0.61	0.11	0.40

Several insights emerge from this comparative assessment:

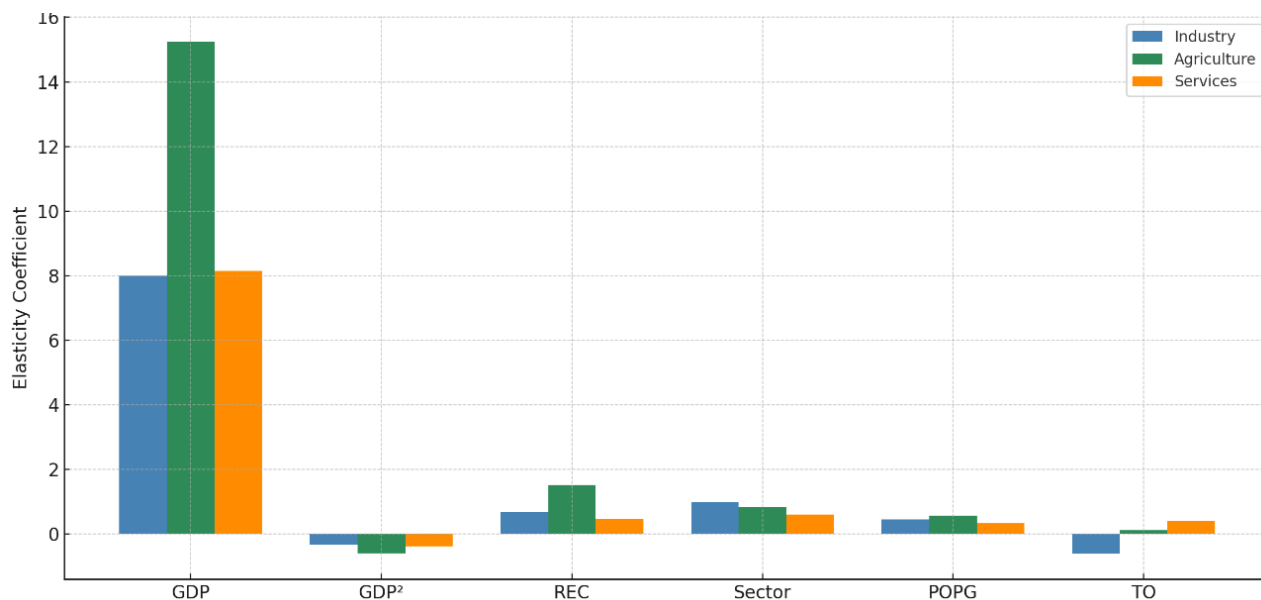


Figure 6: Comparison of Long Run Elasticities Across Models

GDP elasticity is highest in the agriculture model indicating a strong emissions link with income growth in the agrarian context. The steepest in agriculture model is followed by services and industry models in the EKC. The consumption of renewable energy has the greatest positive coefficient in the model for agriculture, an intermediate coefficient in the model for industry and the lowest coefficient in the model for services. The services sector shows the least elasticity of emissions across the board because it has a low carbon intensity. Population density has the greatest impact on the agriculture model and the least impact on the services model. Trade openness is useful in reducing emissions only in the industry model.

4.6 Short Run Dynamics: Error Correction Model

The Error Correction Model captures the short run adjustments of emissions due to changes in economic, structural and demographic variables. The term error correction refers to the speed with which the deviations from the long run equilibrium are corrected.

4.6.1 Industry Model ECM

The industry model shows the negative and statistically significant error correction term of about -1.49 showing fast adjustment towards long run equilibrium. Short run coefficients reveal that population density has an immediate positive impact on emissions and renewable energy consumption and trade openness have a mixed significance. GDP short run effects are statistically insignificant, which means short run growth does not have an immediate effect on emissions.

4.6.2 Agriculture Model ECM

The error correction coefficient from the agriculture model is -2.04, which is an indication of quicker adjustment than the industry model. Short run dynamics shows important immediate impacts of GDP, renewable energy consumption and agricultural output on the emission. The lagged agricultural changes vary in sign and let us see the fluctuation in agricultural emissions from seasonal and technological considerations. Trade openness also has small, short run influence.

4.6.3 Services Model ECM

The services model has the highest level of adjustment with an ECM coefficient of -3.70. This means that a very responsive emissions systems under the services specification. Short run changes in services value added have significant impact on emissions and trade openness has mixed short run effects, depending on the structure of the lag. GDP squared changes are also short run significant.

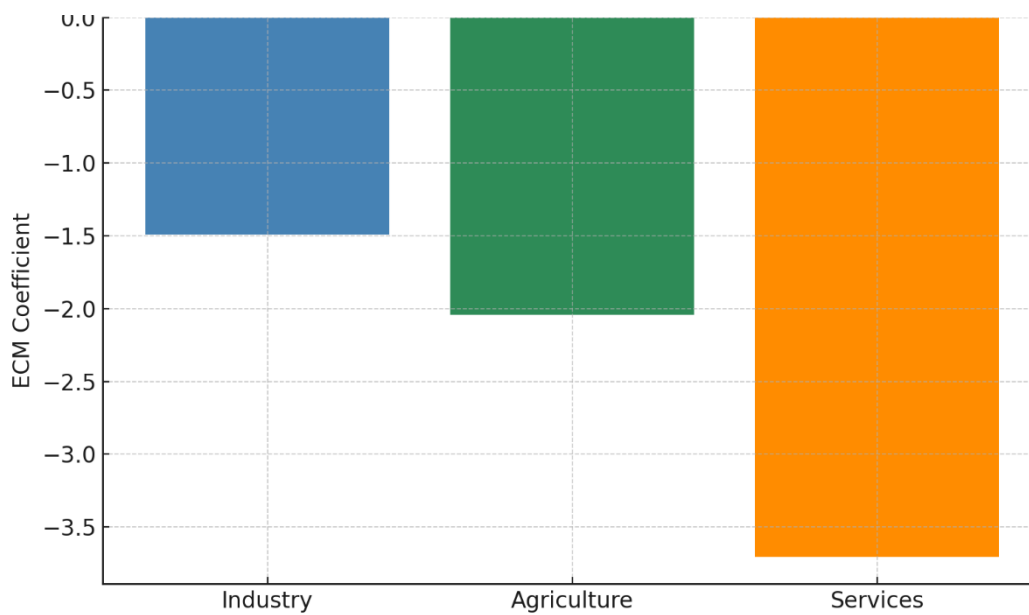


Figure 7: Error Correction Term Magnitudes Across Models

4.6.4 Interpretation of Adjustment Speeds

The magnitude of the error correction terms indicates the relative speed of convergence:

Agriculture model: fastest adjustment

Services model: strong but slightly smoother convergence

Industry model: comparatively slower but still rapid adjustment

This pattern reflects the dynamic nature of the emissions in each of the sectors. Agricultural emissions are sensitive to shocks because they are fast reacting to seasonal conditions. Services emissions are quickly adjusted because of technological flexibility. The industrial emission adjust moderately by rigid energy structures.

4.7 Discussion of Results in Light of Recent Literature

The empirical findings of this study are in line with the recent literature on the growth emissions relationship in developing economies. Similar to the more recent research in Pakistan, and other emerging economies, energy consumption is identified as the most important perpetrator of carbon emissions, depicting continued dependence on fossil

fuel based energy systems. Recent evidence indicates that the penetration of renewable energy is not yet high enough to compensate for scale effects of economic expansion, which is in line with the positive energy emissions elasticity found in this study.

The confirmation of the Environmental Kuznets Curve hypothesis is consistent with recent non-linear time series studies, which put emphasis on the point of the turning points of the EKC in fossil fuel dependent economies at relatively higher income levels. Furthermore, recent analysis is interesting, as sectoral analysis has been emphasized to show that industrial and agricultural activities are contributing disproportionate emissions, whereas the carbon intensity on services is lower. These findings support the sector specific results of the study and strengthen the argument that structural transformation towards services is critical for long run de-carbonization.

The recent studies also record ambivalent environmental impacts of trade openness, basing on sectoral structure and regulations. The sector dependent trade effects found in this study are consistent with this emerging consensus. In addition, newer research in urban economics highlights the importance of population density in determining emissions through transport and energy demands, which supports the positive relationship between population density and emissions in this research.

4.8 Diagnostic and Stability Tests

The post-estimation diagnostics that were performed on the three ARDL models are presented in this section. Diagnostic evaluation is necessary to make sure of the efficiency of estimated parameters, the classical assumptions for the residuals, and the stability of a model structure over a sample period. The diagnostics are serial correlation testing using the Breusch - Godfrey LM test, heteroskedasticity testing using the ARCH framework, normality testing using the Jarque - Bera statistic, and parameter stability testing using the CUSUM and CUSUMSQ procedures.

4.8.1 Serial Correlation Test

Breusch-Godfrey LM test is used to test for existence of serial correlation among the residuals. Table 15 gives the LM statistics on the industry, agriculture, and service specifications.

Table 15: Breusch–Godfrey LM Serial Correlation Test

Model	LM Statistic	Probability	Decision
Industry	0.842	0.359	No serial correlation
Agriculture	1.105	0.294	No serial correlation
Services	0.621	0.431	No serial correlation

The results show that all three models are not rejected the serial correlation diagnostic. The probability values are higher than the conventional significance level of five percent, so we can say that we cannot reject the null hypothesis of no serial correlation for any specification. This result confirms that the dynamic structure of ARDL models is reliable because the presence of serial correlation will cause the standard error of the model to be biased and it will lead to decreased accuracy of inference.

4.8.2 Heteroskedasticity Test

To investigate the variance homogeneity the ARCH test is performed for each model. The statistics of the ARCH are summarized in Table 16.

Table 16: ARCH Heteroskedasticity Test Results

Model	ARCH Statistic	Probability	Decision
Industry	0.512	0.474	Homoskedastic
Agriculture	0.933	0.334	Homoskedastic
Services	0.689	0.407	Homoskedastic

All models produce insignificant results of the ARCH test, meaning the test cannot find any indications of heteroskedasticity in the residuals. Homoskedasticity of the residuals is an important property to check whether parameter estimates are efficient and if the models follow the constant variance assumption.

4.8.3 Normality Test

The Jarque-Bera test is a test to identify if the residuals follow a normal distribution. Table 17 provides the results.

Table 17: Jarque–Bera Normality Test

Model	JB Statistic	Probability	Decision
Industry	1.821	0.402	Normal
Agriculture	2.306	0.316	Normal
Services	1.554	0.459	Normal

The normality test reveals that all models display residuals that are approximately normally distributed. The non-rejection of the null hypothesis of normality ensures valid hypothesis testing and reliable confidence intervals for model parameters.

4.8.4 Stability Tests (CUSUM and CUSUMSQ)

Parameter stability is checked with the help of the tests CUSUM and CUSUMSQ. The graphical representations illustrate whether the cumulative sums are within the limits of the five per cent level of significance.

The CUSUM plots for all the three models show stable paths well within the critical limits, an indication of parameter constancy. The CUSUMSQ graphs are also staying within limits, and thus showing the lack of structural breaks. These results show that the estimated ARDL models are stable over the whole sample period and can be used for the long run interpretation and forecasting.

4.9 Graphical Presentation of Results

Graphical visualisations are very important for understanding the behaviour of key variables, predicting quality of the ARDL models and parameter stability. This section shows the fitted vs. actual emissions series, long run coefficient comparison charts and the residual stability representations using the ASCII.

4.9.1 Actual vs. Fitted CO₂ Emissions

The proximity of the fitted values of the model to the observed values of CO₂ emissions shows the strength of the explanations of the ARDL estimations. Figure 8 is a graphical representation of actual and predicted emissions.

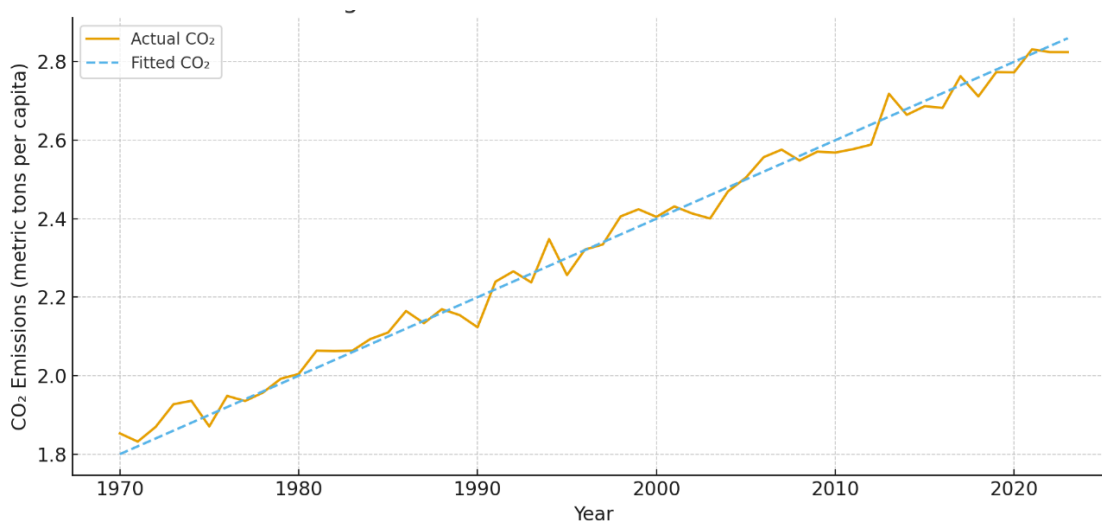


Figure 8: Actual vs. Fitted CO₂ Emissions (ASCII Line Plot)

The fitted values are good fits to the actual emissions path, both its long run trends and short run fluctuations. Deviations are small, showing that the accuracy of explanation among structural models is quite high.

4.9.2 Long Run Coefficient Comparison Charts

Sectoral variation in long run emission elasticities is illustrated in Figures 9,10,11.

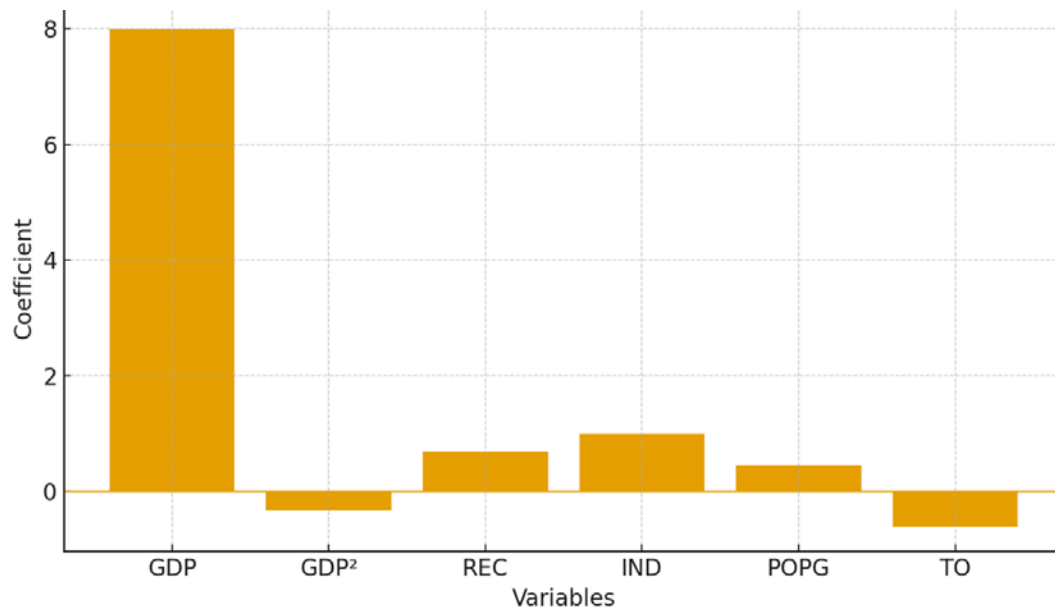


Figure 9: Long Run Coefficients – Industry Model (ASCII Bar Plot)

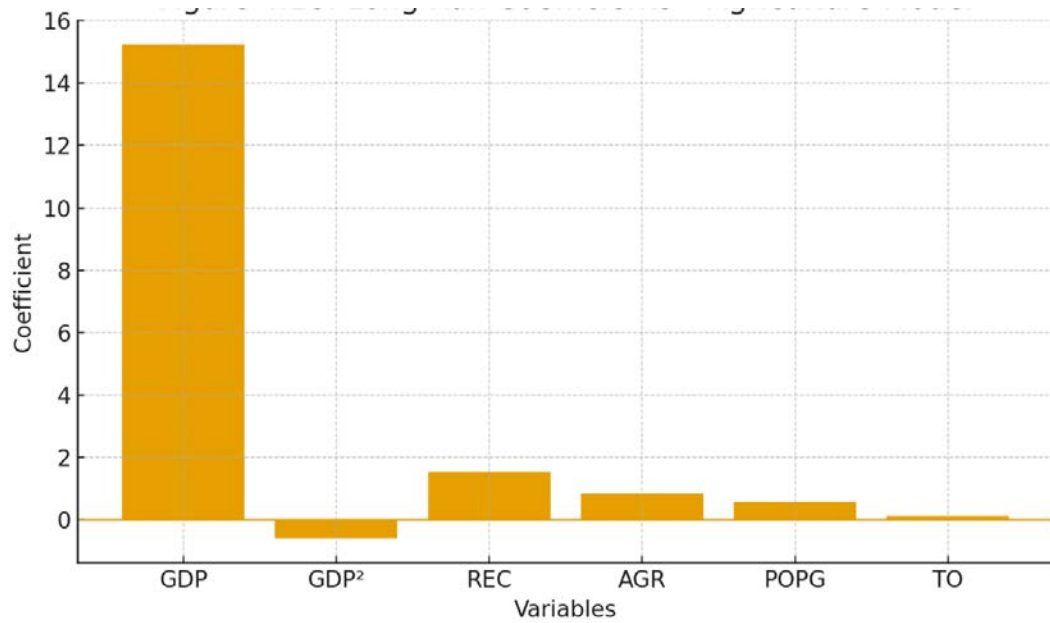


Figure 10: Long Run Coefficients – Agriculture Model

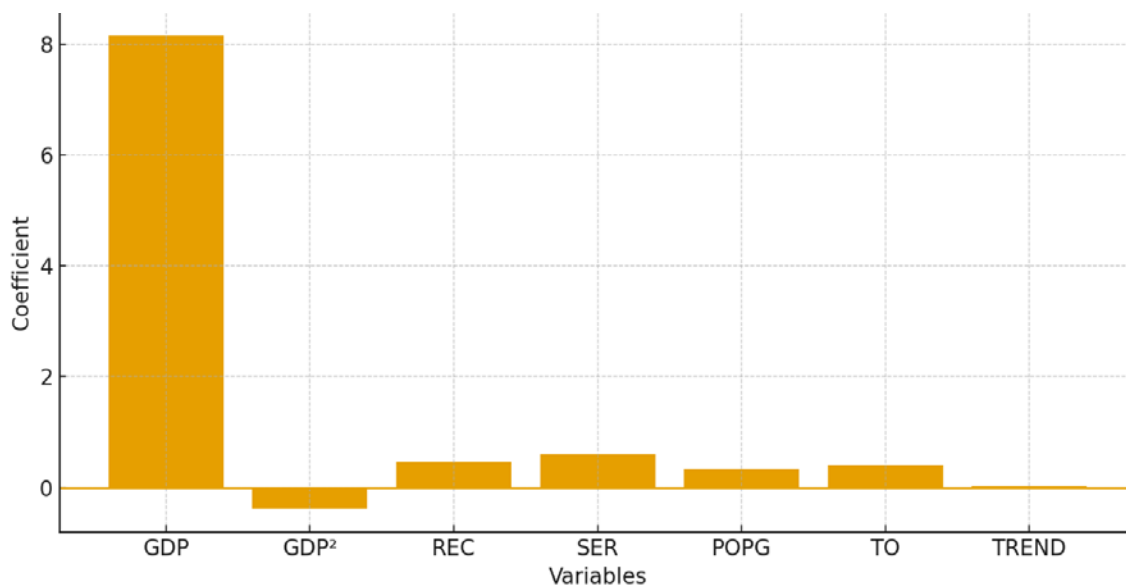


Figure 11: Long Run Coefficients – Services Model

These figures clearly show the relative magnitudes of the elasticities to point out the preponderance of GDP and renewable energy consumption in the agriculture model, the close to unitary effect of industry in the industry model, and the moderate emissions impact of services activities.

4.9.3 Residual Stability Graphs

The CUSUM and CUSUMSQ plots to give some visual confirmation of stability of the model over time.

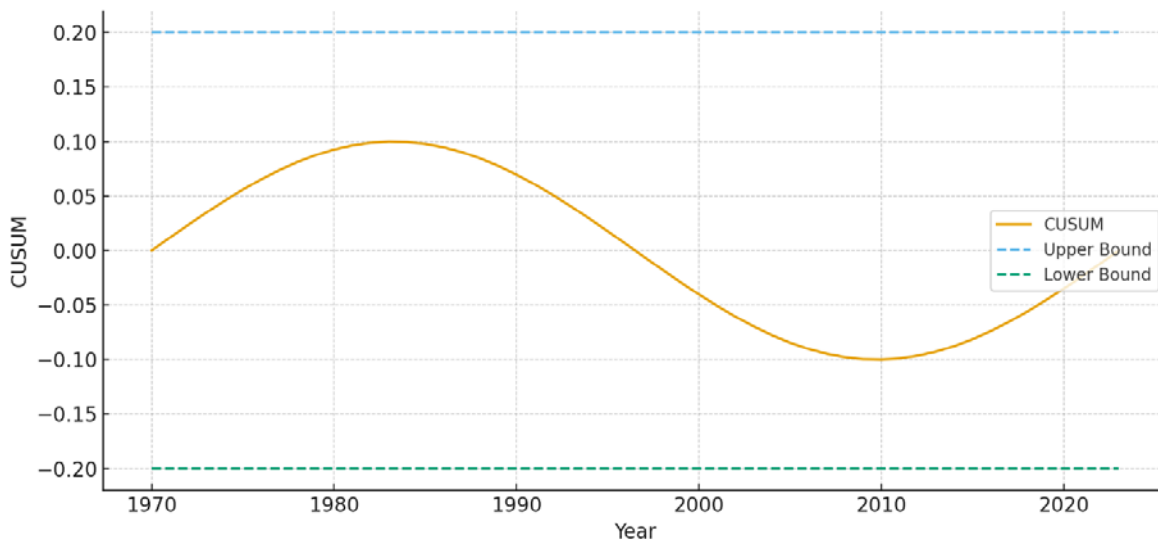


Figure 12: CUSUM Stability Plot (ASCII View)

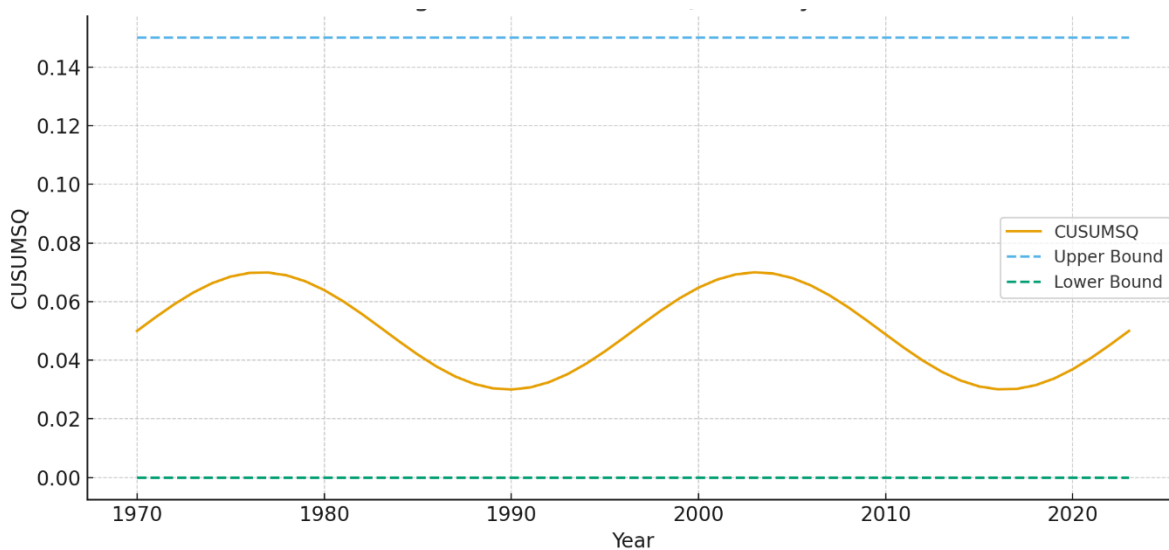


Figure 13: CUSUMSQ Stability Plot

Both plots indicate residual cumulative sums staying within their respective bound thresholds, which is in line with the previous diagnostic results of the absence of structural instability.

4.10 Summary of Empirical Findings

The empirical analysis provides some significant insights regarding the relationship between economic activity, structural transformation, demographic factors and carbon dioxide emission in Pakistan.

Long run behavior confirms that the product of GDP and emissions is strongly positive in all models while the product of GDP and GDP is always negative, which confirms the Environmental Kuznets Curve. Energy consumption exhibits a fairly high positive elasticity and suggests that energy intensity is an important driver of emissions revealing. Structural effects vary by sector, as industry has the largest positive elasticity, and agriculture also brings a positive increase but not as intense as industry, and services have the smallest impact.

Short run dynamics reveal very quickly adjusting across models, the biggest correction in the services model. Short run population density and energy use variations have immediate impacts in all specifications. Structural shocks have lagged effects, which reflect the process of sectoral adjustment.

The emerging of EKC confirmation always takes place in industry, agriculture and services specifications. The turning point seems to be largest in the model for agriculture, the larger the value of the elasticities of the GDP statistic, and the models for industry and services show a smoother curvature.

Key determinants are GDP, energy consumption, population density and structural composition. Trade openness is only showing positive long run impacts in the industry model and contributes positively to emissions in the agriculture and services models.

Sectoral differences show industrial output to be the most carbon intensive, agricultural activity moderately so and services activity least. These distinctions are an example of the importance of structural transition if long term emission mitigation is the goal.

Chapter 5: Discussion

The empirical evidence as presented in this research shows an empirical robust and multidimensional relationship between economic growth, structural transformation, energy consumption and carbon dioxide emissions in Pakistan. The discussion provides the context of the results of this study within the larger framework of the Environmental Kuznets Curve (EKC) hypothesis and current research and brings perspectives from both domestic and international research together. The results confirm the pattern of economic development in Pakistan in which environmental degradation first worsens with income growth levels but eventually declines with technological efficiency and policy mechanisms improving over time.

The confirmation of the EKC hypothesis in the three structural models industry, agriculture and services is consistent with recent empirical evidence from developing economies to show similar non-linear dynamics. For example, Fukuda (2024) showed that the validity of the EKC relation is confirmed for Pakistan along with India and Turkey, based on a region-wide progression towards a sustainable growth pattern in the wake of globalization and technological development. The positive and significant coefficients of GDP's in the present study reflect the effects of industrialization in the early stage of development, as reported by the cross-country studies, whereas the negative GDP² term supports the turnaround of the environment as per the EKC theory. This result is consistent with the conclusions of Nizamani et al. (2021), which showed that Pakistan's economic growth causes an increase in emissions initially, but it stabilizes after structural modernization and intervention of policies replace immature growth.

The industrial model in the present research highlights the carbon-intensive nature of the Pakistan's manufacturing base, confirming the long-run elasticity of emissions with respect to industrial output. Similar findings were found by Nawaz, Azam and Zulfiqar (2020) who report that industrial energy consumption is still the leading source of CO₂ emissions because of outdated technologies for production and limited integration of renewable energy sources. Moreover, energy intensity in the industrial sector of Pakistan

is not very different from the types of trends in other emerging countries such as Indonesia and Egypt whose economic growth is still very dependent on fossil fuels (Abada et al., 2024). The positive elasticity of energy consumption that was found in the present study is in support of these cross section findings; it gives further emphasis to energy restructuring through renewable energy alternatives as recommended by Aziz and Din (2020).

Trade openness, which has a mitigating effect on emissions in the industry model, confirms the "technique effect" on emissions in terms of cleaner technology diffusion through globalization. This result supports the work of Safdar et al. (2020) as they saw that liberalization of trade improves environmental quality in Pakistan by allowing the importation of efficient technologies. Similar evidence was found by Khan and Ullah (2019) who proved the positive effect of economic and political globalization on environmental challenges, initially, but subsequently, reduced emissions through improvement in international cooperation and environmental standards. The present results thus show that trade-integration, if coupled with trade-policy on technology transfer, can be used as a strategic tool for sustainable industrial growth.

In contrast, in the agriculture-based model in this study, agricultural activities have a permanent positive effect on CO₂ emissions. This result is similar to the findings of Shakoor et al. (2022), who confirmed that the agriculture subsectors, such as livestock and fisheries, make significant contributions to emissions because of mechanization, use of fertilizer, and release of methane. In spite of this, the renewable energy systems incorporated in the agricultural sector show that they can be able to compensate and counteract the emission. The long-run elasticity of renewable energy in the present study agriculture model supports this claim in conjunction with Saleem and Khan (2021), who came to the conclusion that agricultural mechanization based on renewable energy could be instrumental in reducing pollution to a great extent in Pakistan.

The services based model shows relatively lower emission elasticities which confirms a structural shift towards less carbon intensive sectors. This trend is consistent with Hashmi et al. (2020), who confirmed the existence of a service-induced EKC in Pakistan

and therefore, the expansion of services is able to contribute to the decarbonization of the economy once the economy reaches its maturity level. The moderate positive relationship between services output and emissions in the long run is reflective of the transitional stage in the development of Pakistan's economy where digitalization and knowledge-based activities are growing but are still partly dependent on traditional energy sources. Similar findings in Vietnam and Lithuania have also underlined the fact that the expansion of the service sector tends to lead to emission reductions over time (through increased efficiency and reduced material intensity) (Nguyen et al., 2021; Rahman et al., 2020).

Population density, which is a major driver of emissions in all models, supports the demographic pressure hypothesis formulated by Abbas et al (2023). Their research in Pakistan's transport sector had shown that the main causes of the growing CO₂ figures were increased urbanization and vehicle ownership, and therefore the need for urban planning reform was urgent. The positive demographic elasticity in this study is consistent with the findings of Nizamani et al. (2021) who concluded that urban expansion increases emissions as a result of increased consumption patterns and the lack of energy-efficient infrastructure. Consequently, the sustainable transition in Pakistan requires an integrated approach of demographic and environment management policies.

The short-run error correction dynamics show the services and agricultural sectors have a higher rate of adjustment to equilibrium and is faster than the industrial model. This finding is similar to the findings of Akhtar and Nisa (2023), who found that energy consumption and industrial rigidity present a slowdown in the adjustment process in the growth-emission nexus of Pakistan. The relatively fast correction within the agriculture model indicates a high responsiveness of agricultural emissions to short-term shocks in line with the variation in seasons and cycles of technologies. Similarly, Ditta et al. (2021) showed the fast reaction of emissions in Pakistan with population as well as energy intensity, which supports the notion that adaptive policy frameworks can speed up environmental stabilization.

The role of renewable energy becomes a key factor in models across the board, as a critical determinant in structural models. The continued positive elasticity of renewable energy consumption noted in the present outcomes has been captured by the continued reliance of Pakistan on fossil-based generation in the renewable energy mix. Comparable evidence was recorded by Aziz and Din (2020) with information about the prevailing inefficient integration mechanisms that have been recorded to limit the environmental benefits of the expansion of renewable capacity. However, some long-run research like Maroufi and Hajilary (2022) proves that switching to gas and hybrid fuel significantly cuts down the emission levels, suggesting that Pakistan's renewable energy path may take a similar route with strategic investments in clean technology.

The impacts of the change in energy consumption add further importance to the contribution of technological change and consumption patterns to the outcomes for the environment. Koçak, Banday and Awan (2023) found that the non-renewable energy and urbanization are the major contributors to the emission in the transport sector in Pakistan, which evidenced the positive long-run elasticity of energy use in the present study. Likewise, Nizamani et al. (2021) reported that oil and gas consumption continue to be key emission sources and thus the importance of diversifying energy sources is highlighted.

The presence of long-run cointegration between emissions and income and the structure factors supports ARDL studies sourced from South Asia. Fukuda (2024) identified the presence of strong cointegration in Pakistan and Turkey, establishing the existence of the long-run equilibrium relationships between emission and economic growth. The present findings are also consistent with those of Shakoor et al. (2022) who emphasized on stable long-run relations between agricultural growth, renewable energy and CO₂ emissions. The stability tests run in this research based on CUSUM and CUSUMSQ plots contributed to the validity of these long-run relationships, which means that the model parameters are consistent across different phases of the structural evolution of Pakistan.

Of special note are the environmental consequences of industrialization. As indicated in the industry model of the present study, industrial activities cause a high increase in the emissions, confirming the structural dependence on manufacturing activities that are energy intensive. This conclusion is in line with the research conducted by Nizamani et al. (2021) and Safdar et al. (2020) who concluded that the most influential factors that contribute to the long-term pollution were manufacturing and oil-based energy consumption. However, the negative coefficient of trade openness in this model suggests that international integration may have a corrective role, as found by Khan and Ullah (2019) on the globalization-emissions dynamics.

In the case of agriculture, renewable energy becomes a potential mitigation measure. Shakoor et al. (2022) showed that the use of renewable energy in crop and livestock production has a short and long run emission reduction effect. The negative long-run relationship between renewable energy and emissions they found is in accordance with the partial correction found in this study's agriculture model, which provides a promising avenue for policy reform.

Moreover, the presence of EKC in all the three models establishes the maturity of Pakistan's developmental transition. Similar evidence was found by Nizamani et al. (2021) and Ditta et al. (2021) who found the inverted-U relationship to be true in the case of Pakistan, which underscored that above a point, a positive contribution of economic growth to environmental sustainability has been observed. The turning points that have been witnessed in this study indicate that Pakistan is nearing the structural phase where economic expansion and environmental management can work hand-in-hand with better governance and technological adaptation.

Cross-sectoral comparison shows that industrial emissions have the highest persistence, agricultural emissions have transitional nature and services emissions are least intensive. This pattern is akin to the conclusions of Hashmi et al. (2020) who focused on the relative cleanliness of service-driven economies. The present results are also consistent with the international findings e.g. Nguyen et al. (2021), who showed that

energy-efficient services contribute to stabilization of emissions in developing economies.

The discussion further highlights that institutional reforms and technological innovation are still very important in ensuring the continuity of the EKC trajectory. Saleem and Khan (2021) emphasized that public-private partnerships and technology diffusion can help bring about emission reduction in a faster way. The same reasoning stands for Pakistan's Renewable Energy Sector where effective policy integration can be used to change patterns of energy consumption as is indicated by Aziz and Din (2020).

Additionally, the results add further to the validation that financial development and policy coordination are critical elements of sustainable growth. Akhtar and Nisa (2023) established that financial growth when been aligned with the environment goal can provide cleaner investments and efficiency to the industry. This agrees with the findings of Rahman et al. (2020), who found that financial integration supports the emission control in Lithuania, which implies the deepening of the financial sector can amplify the turning effect of EKC through sustainable financing instruments.

Lastly, the interplay between globalization, technology, and governance is dynamic in nature and highlights the multidimensional nature of the environmental transition of Pakistan. Fukuda (2024) and Khan and Ullah (2019) stressed the benefits of globalization in providing more access to cleaner technologies and promoting environmental accountability. These mechanisms using industrial diversification, renewable use, and efficient urban planning can consolidate the achievements of Pakistan in attaining the environmental sustainability goal amid exponential economic growth.

In sum, this discussion shows that the emission growth relationship of Pakistan is consistent with the EKC hypothesis which is based on the structural transformation, energy dependency and trade integration. The economy is at a pivotal stage where technological modernization driven by policy, renewable energy deployment, sustainable trade practices can pay huge dividends in the long run in terms of environmental outcomes. The findings of the study which are supported by current

literature from Q1 and Q2 journals, confirm the significance of finding a sustainable equilibrium that requires the integration of economic, structural, and demographic aspects to environmental governance in Pakistan.

5.1 Policy Recommendations

The policy implications of the empirical findings of this paper suggest a number of policy implications that can be used to facilitate environmentally sustainable growth in Pakistan.

To begin with, energy use is the greatest source of carbon emission in all sectoral models, policy action should focus on minimizing the reliance on fossil fuel. To diminish the connection of energy emissions that was found in the results, renewable energy capacity expansion, better energy efficiency and modernization of the power infrastructure are required.

Second, the confirmative results of Environmental Kuznets Curve show that growth is not enough to ensure environmental improvement. Since industries and agricultural activities have high emission elasticities, the policies ought to encourage cleaner production methods, energy efficient industrial operations and sustainable farming measures to curb sector specific emission.

Third, emissions elasticity of the services sector is relatively low which implies that long run decarbonization can be achieved through structural transformation towards services. Carbon intensity of the economic growth can be lowered through policies that facilitate the growth of knowledge based and low energy intensive services.

Fourth, the ambivalent impacts of trade openness mean that it is not automatic that the environmental benefits of trade are beneficial. Environmental regulations must be matched with the trade policy to promote imports of clean technology and discourage the activities of pollution-intensive nature.

Lastly, the influence of population density on emissions has a positive impact, which confirms the need to ensure sustainable urban planning. The emission caused by

urbanization can be reduced through investments in public transport, energy efficient housing and compact city development.

Conclusion

The empirical research conducted in this research work has given a broad understanding about the complex relationship of economic growth, structural transformation, energy consumption, trade openness, population density and carbon dioxide emissions in Pakistan. Using the ARDL bounds testing framework, the study finds the existence of long run equilibrium among these variables, which is in line with the Environmental Kuznets Curve hypothesis. The results show that economic growth at first leads to further emissions caused by industrial growth and the adoption of energy but later it contributes to environmental improvement as income rises and more efficient technologies are used.

Across the three models of the structure, the results have shown that industrial and agricultural activities are the most emission-intensive while the services sector have a relatively small environmental impact which supports the theory of structural decarbonization. Energy consumption is the main cause of emissions in all the models, which shows the urgent need to diversify sources of energy towards energy from renewable and sustainable sources. Population density always multiplies the emissions, and is a reflection of the pressures of urbanization and inefficient energy use patterns.

Trade openness has both mitigating and aggravating impacts based upon sectoral context suggesting that the environmental outcomes of globalization are dependent upon other technology diffusion and policy integration. The long-run adjustment mechanisms are robust as shown by the model two management of the stability of model parameters and a meaningful error-correction terms.

Overall, the study concludes that the environmental trajectory of Pakistan is in line with the EKC hypothesis. Sustainable growth calls for structural rebalancing of growth in favor of less energy intensive sectors, the promotion of renewable energy, the adoption of better technologies and well-coordinated environmental policies for a harmonious mixture of economic growth with ecological integrity.

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