Dynamic linkages between Environment and Oil Consumption and their impact on Economic Growth

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Abstract - The dynamic links between Pakistan's economic growth, fuel consumption (FC), carbon dioxide emissions (CO_2), and population growth (POP_G) between 1996 and 2022 are examined in this paper. We verify symmetric cointegration between these variables using an ARDL bounds testing approach (F-statistic = 4.530 > 4.35 critical value), indicating a stable long-run equilibrium. One of the primary decisions was that, according to the GDP-Environment Nexus, GDP shows a high positive connection with CO_2 (0.967) and POP_G (0.966), but a low correlation with FC (-0.031), indicating that Pakistan's growth is still energy-inefficient and emission-intensive. Population-Driven Dynamics: Population growth (POP_G) has a substantial correlation with CO_2 emissions (0.970) and a long-run elasticity of 2.22 with GDP (ARDL), suggesting that demographic pressures increase both economic output and environmental deterioration. The severe emission dependency of Pakistan is revealed by the CO_2-GDP elasticity of 69.38. Asymmetric Energy Effects: Due to structural inefficiencies in energy use, FC exhibits varying short-term effects on GDP (lagged range from -4.23 to +3.82). Rapid annual adjustment to equilibrium is indicated by the error correction term (-0.677). The findings highlight how urgent it is to match Pakistan's high CO_2-GDP elasticity (69.38) with its Renewable Energy Policy 2030 and NDC ambitions. It is advised to implement population-sensitive climate measures in order to lessen the trade-off between emission-intensive growth and agricultural production, which now accounts for 24% of *GDP. In Pakistan's development framework, the study offers empirical support for policymakers to create integrated energy-population-climate plans that prioritize sustainable urbanization and the transition to renewable energy.*

Key Words: CO2 Emission, Population Growth, GDP, Fuel Consumption, ARDL Model

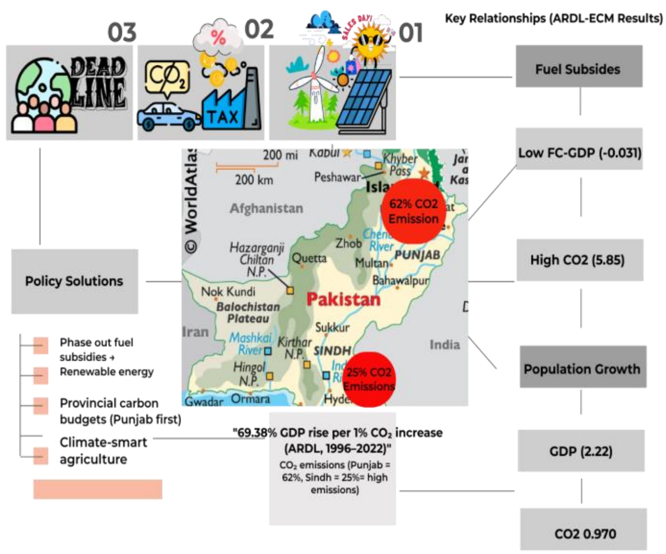

Figure 1: Graphical Abstract: CO_2 emissions drive Pakistan's GDP growth, but fuel subsidies weaken policy responsiveness (ARDL-ECM results, 1995–2022)

1.INTRODUCTION

Nearly all of the world's economies agree that business activity has contributed to their growth over the past century. These activities not only helped nations flourish economically, but they also significantly increased oil consumption and CO2 emissions. The relationship between economic expansion and environmental deterioration as assessed by carbon dioxide was examined in a recent study. The global trend indicates that some countries have withstood economic booms despite rising CO2 emissions. Concerns over the "Low carbon and green growth" approach, however, have grown. In the current era of globalization, GDP growth accounts for roughly 8% of global CO2 emissions, which in turn is responsible for stumping up global carbon emissions [1]. Enacted on December 6, 1997, the Pakistan Environmental Act aims to protect, conserve, restore, and enhance the environment. The foundation of Pakistan's environmental policy is a participatory approach to using stated platform to achieve sustainable development goals [2]. A new record high of 419.3 parts per million, or "ppm," of carbon dioxide was recorded in 2023. The increase from 2022 to 2023 was 2.8 parts per million, marking the

12th consecutive year that the atmospheric concentration of carbon dioxide rose by more than 2 parts per million [3]. The estimation demonstrates how economic activity has caused carbon dioxide levels to fluctuate over time, from 365 parts per million in 2002 to over 400 parts per million today. In addition to undermining attempts to slow down global warming, this phenomenon presents long-term sustainability issues for Pakistan's economic growth. In 2023, the average annual carbon dioxide at Mauna Loa Observatory in Hawaii, where the modern carbon dioxide record started in 1958, was 421.08. 93 [4].

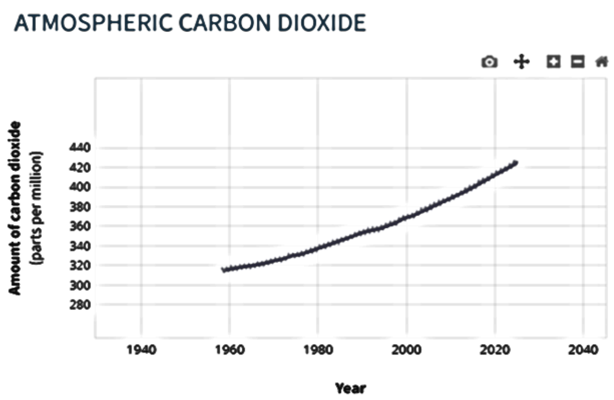

Chart -1: Atmospheric Carbon Dioxide

Since 1958, the station's monthly average carbon dioxide readings in parts per million (ppm) have been displayed in this graph. Summer vegetation growth in the Northern Hemisphere lowers atmospheric carbon dioxide, while winter decomposition raises it, causing the seasonal cycle of highs and lows (little peaks and troughs). Human activity is the primary cause of the long-term trend of growing carbon dioxide levels. Every year: May has the greatest monthly value at Mauna Loa. Carbon dioxide reached a new high of 424 parts per million in May 2023. Based on NOAA Global Monitoring Lab Mauna Loa monthly mean data, the NOAA Climate.gov image [5].

Although economic growth is crucial for development, this study contends that it also significantly contributes to CO2 emissions; as a result, policies and methods that strike a balance between environmental protection and economic growth are necessary for sustainable economic growth in Pakistan. In addition to discussing the theoretical frameworks that support our knowledge of energy consumption in connection to economic development, it also conducts an empirical investigation into how these dynamics affect the nation's environmental performance.

There has been much debate and contention on the causal relationship between oil consumption and economic growth ever [6], since Kraft and Kraft's seminal paper in 1978. Nevertheless, this experience evidence shows different levels of unidirectional or bidirectional connectedness, as well as no connectivity at all. A nation's energy supply, degree of development, the effectiveness of its policy on recycled energy, energy consumption, and other variables all affect the consequences. This explains why the relationship between energy use and economic growth continues to be a topic of discussion and a top goal for policy officials from both industrialized and emerging economies. Furthermore, they argue that because energy can be a restricting factor along with a variety of other production constraints, energy consumption is strongly linked to a country's economic progress. The relationship between economic growth and energy consumption is so complex that the findings vary not only among nations but also across econometric methodologies. The causal relationship between economic growth and environmental pollution, which causes CO2 emissions, is another aspect of the global warming problem that is high on the research and strategy agenda. On the one hand, this is a result of growing concern about the foundations of scarce energy, and on the other, it is a new paradigm for a green economy. The following make it vital and necessary to look into whether rising energy consumption and economic growth result in higher levels of environmental pollution.

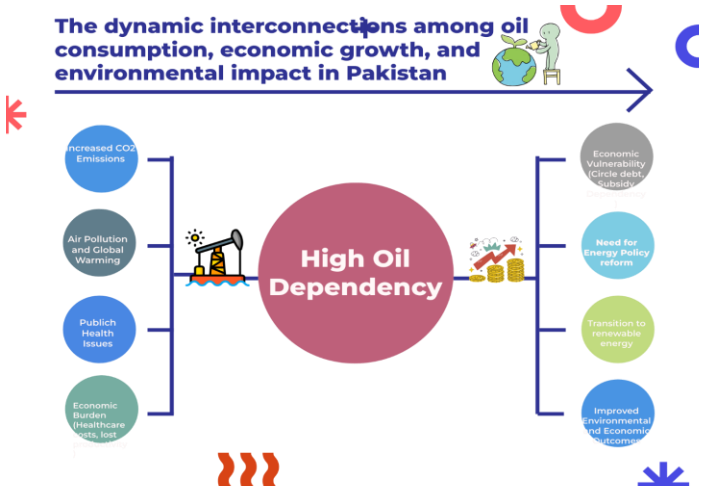

Fig -2: Flowchart illustrates the dynamic interconnections among oil consumption, economic growth, and environmental impact in Pakistan.

Pakistan's energy needs are mostly met by oil, just like those of many other developing countries. The nation's economy is heavily reliant on the energy supply, and oil consumption is significant in this regard. In Pakistan, 54% of all energy production comes from natural gas and oil. 37.7% of all energy is used by the industrial sector, followed by homes (22.2%) and the transportation sector (32.2%). Meanwhile, consumption is 2.6% in the public sector, 2.5% in the commercial sector, and 2.3% in the agricultural sector [7]. The energy sector is essential to the expansion of countries' economy. However, the country faces numerous challenges in the energy sector, including limited access to alternative energy sources, poor infrastructure, and a lack of local resources.

International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 12 Issue: 04 | Apr 2025 www.irjet.net p-ISSN: 2395-0072

Pakistan's oil use has had a major effect on the environment and the country's GDP. According to the latest data from the U.S. Energy Information Administration (EIA), Pakistan's oil consumption in 2020 will be 303,000 barrels per day (b/d) or less. This is a little decrease from the 2019 oil consumption level of 314,000 barrels per day. The expansion of the industrial sector and population growth have been the main causes of this consumption rate's steady increase throughout time. The transportation sector is clearly the largest oil consumer in the country, accounting for 43 percent of total oil consumption. The industrial sector is the largest consumer, followed by the household sector, which mostly uses oil for cooking and heating. The elevated consumption has resulted in much higher carbon dioxide emissions and an increase in the nation's GDP. However, it should be noted that the COVID-19 pandemic, together with the ensuing lockdowns and travel restrictions, undoubtedly altered the amount of oil consumed in Pakistan and other countries worldwide [8]. The burning of fossil fuels to meet the country's energy demands has resulted in a sharp rise in carbon dioxide emissions. The environment has been affected as a result, which has accelerated global warming and worsened air quality. Increasing oil consumption also affects Pakistan's GDP because consumers pay for energy production. As a result, labor and product expenses have increased, and purchasing power has decreased. In the end, Pakistan's oil use has detrimental effects on GDP and carbon dioxide emissions, which need to be addressed to protect the country's economy and environment. Oil use and its effects on the economy and climate will be tightly controlled as Pakistan continues to focus on realistic developments. Pakistan is heavily reliant on oil imports to meet its energy needs because it has little domestic oil production despite the country's increasing oil consumption. Nearly 85% of the country's oil needs are imported, primarily from the Center East. This dependence on foreign oil imports exposes the nation to fluctuations in global oil prices, which can have a significant impact on its economy as a whole.

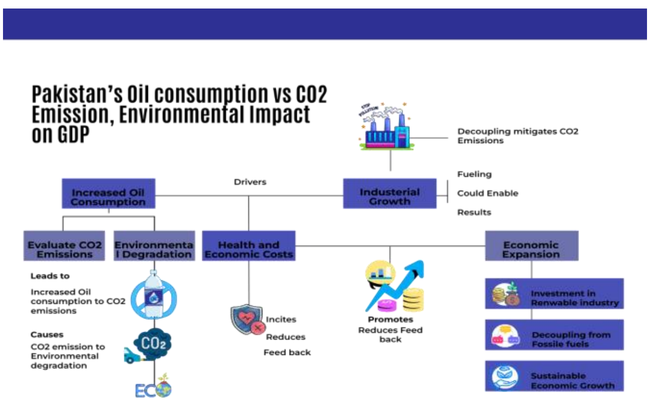

Fig -3: Pakistan's Oil consumption vs CO2 Emission, Environmental Impact on GDP

Numerous studies have examined the connection between GDP growth and CO2 emissions. Pakistan has significant levels of air pollution and carbon emissions as a result of its fast industrialization and economic growth. Many of them employ a different method that shows a thriving economy and a rise in CO2 levels in the state. There are still a few reasons why more research in this area may be essential, regardless of how much has been examined on the topic of the strong connection between Pakistan's climate, oil use, and economic development. Emerging trends: Economies and economic conditions are always shifting, and new trends and problems may surface that need more research to fully understand their impact on Pakistan's oil use and financial growth. Further research is anticipated to examine the specific impact of the coronavirus pandemic on Pakistan. For example, it essentially impacts global oil consumption and economic growth. The relationship between climate, oil use, and financial development can be impacted by the unique ways that each country sets explicit factors, even while there may be general trends and examples that apply to other countries and regions. In order to understand what these factors specifically signify for Pakistan; more research is therefore anticipated. Ideas regarding a strategy: Research on Pakistan's environment, oil use, and economic growth can yield important arrangement recommendations for governments, institutions, and other partners [9]. Policymakers might approach more potent and contemporary evidence that can help them navigate and help them develop more workable arrangements and systems by spearheading more research. Information gaps: To fully understand the strong connection between Pakistan's climate, oil use, and financial development, there may still be important knowledge gaps that need to be filled despite the existing array of research. We can identify and fill in these gaps and promote a more complete and sophisticated understanding of the problem by guiding future research. The statistical significance of the symmetric association between economic growth and carbon emissions was validated by our findings. Reducing CO2 emissions and achieving sustainable economic growth are major challenges for Pakistan, a developing country.

In order to accomplish the ultimate goals of long-term growth and worldwide wealth, the following Objectives are established for industrialization and developing issues:

1. Describe the relationship between economic factors and environmental factors.

2. Ascertain which element contributes most to GDP production and growth.

3. Determine Pakistan's oil industry's advantages and disadvantages with relation to CO2.

Numerous future fields will benefit greatly from our research: The contribution of environmental elements to GDP is balanced. ii) Making inferences about overall CO2 emissions per unit is a considerate move. iii-Enabling the calculation of the CO2 rate in different places (for collapsing). IV: Identifying certain diseases, such carbon dioxide-absorbing plants. V. Positive administration enumerated GDP's advantages.

The remainder of the document is structured as follows: Sect. 2 provides an overview of the existing literature. Section 3 presents the empirical model, data, and methodology. Section 4 reports the observed results and comments. The final portion contains the conclusion and policy recommendations for Pakistan's economy.

2.LITERATURE REVIEW

There has been substantial discussion in the literature regarding the connection between economic growth and oil use. While some research indicates a negative link or no relationship at all, others imply a positive correlation with oil usage [10]. Our study uses the ARDL approach based on FDI to illustrate the link between GDP, F.C., P.G., and CO2. The empirical findings demonstrate a strong symmetric relationship between the existence of an ARDL model at various levels. A paper based on economic growth and CO2 emissions, along with other metrics we've covered here, has been distributed. Several earlier studies that examined the connection between CO2 emissions and economic growth using a variety of metrics such as Health expenditure [11] Transportation [12], [13], oil and coal consumption, [14], [15] and, Trade openness [16], [17] and [18] and Energy use studies by [19],[20], [21], and discuss fossil fuels [22], [23], and [24].

2.1 Energy-Growth Nexus and Environmental Sustainability

Two major theoretical frameworks underpin the relationship between energy usage and economic growth. According to the Environmental Kuznets Curve (EKC) Hypothesis, pollution rises with industrialization at first [25] but eventually falls as economies shift to cleaner technologies and more stringent regulations [26], [27]. This suggests that economic growth and environmental degradation have an inverted U-shaped relationship. In Pakistan, where fossil fuels will account for 72% of the country's energy mix in 2023, the EKC framework emphasizes the conflict between sustainability objectives and growth-driven emissions [28]. Pakistan has not yet reached the EKC's turning point, according to recent research [29], with CO_2 emissions still rising in tandem with GDP. Decoupling models evaluate whether economies can expand without escalating environmental concerns by Tapio approach [30], [31]. Pakistani empirical data shows weak decoupling, mixed decoupling states, and GDP growth outpacing emissions because of agricultural dominance [32],[33]. Emissions intensity increased due to industrialization, coal-based energy, and extensive negative decoupling [34], which reversed benefits [35]. Other Asian economies that have successfully decoupled [36] indicate that policy-driven solutions (such carbon pricing and foreign direct investment in renewables) may be able to balance sustainability with growth in Pakistan. The universality of the EKC is questioned by recent work [37], which points out that structural variables (such as energy subsidies and path dependency) may postpone the turning point in economies that rely on fossil fuels, such as Pakistan. Dynamic Decoupling: Recent research [38] highlights the need for multi-sectoral strategies by using LMDI decomposition to relate Pakistan's emissions growth to population growth (40%), energy intensity (35%), and GDP per capita (25%) [39]. In contrast to previous asymmetric (NARDL) or panel-based techniques, this article tests symmetric impacts of CO_2 and energy use on GDP via ARDL, extending the debate [40]. We evaluate whether Pakistan's EKC trajectory is accelerated or mitigated by foreign investment [41].

2.2 Empirical Contributions from International Experiences

Although experiments with the integration of renewable energy show that higher shares of clean energy consistently correlate with reduced dependence on fossil fuels, empirical evidence from international studies, especially across Europe, reveals a persistent reliance on fossil fuels, with oil often dominating national energy mixes [42], [43]. Although mainly drawn from European contexts, these findings provide important insights for Pakistan's energy policy issues, as high import prices for fossil fuels worsen long-term energy shortages and economic vulnerabilities [44]. Using the decoupling index, we examined the connection between home CO2 emissions and economic development. According to the study's findings, home CO2 emissions in China initially decreased somewhat before increasing quickly [45]. Overall decoupling states have demonstrated differences, some of these variables include population size, economic growth per capita GDP, technological progress, and CO2 emissions, while the other issues include misspecifications, sustainable growth, and carbon reduction all at once. examined the connection between CO2 emissions, health spending, and economic growth [46], [47]. It is determined that, with the exception of the nations in the low-income category, there was a reciprocal relationship between economic growth, health spending, and CO2 emissions in all of the chosen nations [48]. According to Alshehry and Belloumi, exports, foreign direct investment, carbon emissions, and the use of renewable energy all affect economic growth. It shows that economic growth increases as carbon emissions and foreign direct investment rise [49]. The study uses Unrestricted Error Correction Models and an ARDL bounds testing technique to cointegration to quantify the link between income and CO2 emissions per capita [50], [51]. Different model parameters are calculated to account for the independent impact of various elements identified as drivers of distinct dynamics of CO2 emissions along the growth route on CO2 emissions per capita [52], [53]. To examine the long-term relationship between CO2 emissions and real GDP per capita, real GDP per capita squared term, energy consumption, urbanization, trade openness, and financial development, the chosen time series are subjected to the error correction method (ECM) and the bound testing approach to co-integration with structural break (ARDL) [54]. The long-term association revealed that carbon dioxide emissions and GDP per capita were significantly correlated, but that the relationship between GDP per capita and the usage of fossil fuels and renewable energy sources was negatively correlated [55].

Environmental quality and economics are closely related, and carbon emissions continue to be one of the most hazardous environmental problems in the world. Both local and international governments are creating programs to deal with this issue [56], [57], [58]. Globalization and carbon dioxide emissions at the middle and high quintiles are positively correlated, according to a study that uses quintile-on-quintile regression to examine the dynamic relationship between financial development, economic growth, and globalization on carbon dioxide emissions [59], [60]. Many countries have accelerated their transitions to low-carbon energy systems because research continuously links increased reliance on fossil fuels to negative environmental effects, such as increased CO_2 emissions and declining air quality [61], [62]. European nations who have made wind and solar expansion a priority, for example, have not only decreased emissions but also improved energy security [63]. This is important for Pakistan, where energy shortage continues to be a major barrier to economic growth [64]. These global experiences highlight how adopting renewable energy may reduce economic risks and environmental degradation at the same time, giving Pakistan a strategic road map to deal with its dual problems of energy insecurity and unsustainable growth patterns. In order to help Pakistan, decouple economic growth from rising emissions and improve long-term resilience against global energy market volatility, policy reforms that incentivize clean energy investments, grid modernization, and energy efficiency measures are urgently needed. This is demonstrated by the contrast between economies that rely on fossil fuels and those that have successfully integrated renewables [65].

2.3 Synthesis of Theoretical Perspectives

When combined, the EKC and decoupling models offer a thorough framework for examining the relationship between economic growth, environmental effects, and energy consumption, specifically, oil consumption. panel cointegration tests and pooled mean group ARDL (PMG-ARDL) methodologies to examine the effects of energy consumption, economic growth, urbanization, and energy consumption on carbon emissions [66], [67], [68]. The model was enhanced using the relationships mentioned above, and the results show that urbanization has no discernible impact on the quality of the environment over the long or short term [69]. The study's analysis aimed to reveal how CO2 emissions affect population growth, the use of fossil fuels, and energy consumption. The most developed nations in the world have been the focus of efforts to achieve sustainable economic growth [70], [71], [72]. According to the current study, which examined 29 OECD nations, export diversification increases greenhouse gas emissions while having a negative impact on carbon emissions [73], [74]. Oil consumption has historically fueled economic growth and industrial activity, but these growth trends have also resulted in a startling rise in CO2 emissions and environmental damage [75]. The central idea of our conversation is this duality. Since carbon dioxide is the most important factor influencing climate change and poses a serious threat to human health [76], [77], it is important to look into the relationship between CO2 emissions, economic growth, energy consumption, and urbanization in the ECO member countries [78]. The correctness of the turning point was validated by the estimation of the environmental Kuznets curve (EKC) for the ECO in both the short and long term [79]. The two-way causal relationship between CO2 and economic growth, as well as between energy consumption and economic growth and urbanization, is demonstrated via the DH causality technique [80], [81]. The body of research indicates that the connection between CO2 emissions and economic growth is intricate and ever-changing [82], [83]. GDP and technology during the ten-year period, the study's findings indicate that technology is far more valuable than foreign direct investment (FDI), which is good for GDP growth [84], [85]. The relationship between oil consumption, economic growth, and their effects on the environment can also be influenced by other factors, such as economic policy and political instability [86].

By providing thorough empirical data and going over policy implications pertinent to Pakistan's current energy situation, the following sections of this article expand upon this theoretical framework.

3. METHODOLOGY AND MATERAILS

Supplementary The unit root test approach, developed by Dickey and Fuller in 1981, is used to identify stationary and non-stationary variables. GDP, FC, CO2, and P.G. are the stationary levels of the variables at the first level of difference that are displayed in the table. Co. Pesaran et al. (2001) employ integration analysis to execute the ARDL bound test. To ascertain the symmetric bounding between variables, the ARDL Bound test is utilized. To determine whether there is a symmetric relationship between GDP, FC, PG, and CO2 for Pakistan, ARDL is used in this study. Shabaz and Sinha, as well as Chin Ozden and Emarh Bese in 2011 and 2019, respectively, claim that the ARDL methodology is frequently employed in EKC literature. Fuel Consumption (FC): Price-inelastic energy demand in Pakistan (subsidies reduce responsiveness, for example) may be the cause of the insignificance ($p > 0.10$). Population Growth (POP_G): In developing economies, where demographic changes have delayed economic effects, this lack of relevance is consistent [87].

3.1 MODEL SPECIFICATION

Following the determination of co-integration by the ARDL limits test between variables, the short and long-run coefficients of the variables are calculated using the ARDL-ECM (correction model). Breusch Godfrey examines the model's stability. test for serial correlation. The Ramsey Reset Test, C-test, BG test, C-test, and normalcy test. This study uses a single model. The model is in line with the literature's EKC reduced models. This study looks at Pakistan's GDP (per capita), F.C. (thousand metric tons), CO2 (in KT), and P.G. (per capita). For this model, the estimated parameters P0, P1, P2, and P3 are employed, and the error term ϵt is used, where t is the time index for Pakistan. Based on calculations and the availability of data from the data source, the analysis's time frame is set between 1995 and 2022. The US Energy Administration provides the fuel use data, while the World Bank provides the other data.

3.2 ECNOMETRIC TECHNIQUES

$\text{Ln (GDP)} = P_0 + P_1 \text{ In (FC)}_t + P_2 \ln (CO2)\, t + P_3 \ln (PG) + \epsilon_t$…………………………………. (A)

ARDL Model is given below,

$\Delta \ln (GDP)t = Vo + V_1 \ln (GDP)_{t-1} + V_2 \ln (CO2)_{t-1} + V_3 \ln (P.G)_{t-1} + V_4 \ln (F.C)_{t-1} + \Sigma^e{}_{i=1} V_{5i} \ln GDP_{t-I} + \Sigma^f{}_{i=0} V_{6i} \ln (CO_2)_{t-1} + \Sigma_{i=0} V_{7i} \ln (P.G)_{t-I} + \Sigma_{i=0} V_{8i} \ln (F.C)_{t-I} + VECM\ t{-}1 + \mu_t$ ………………………(B)

V_1, V_2, V_3, V_4 are long-run co-efficient while V_5, V_6, V_7, V_8 are representing the short run co-efficient, with residual, of,

H_o, Hypothesis of no co-integration= $V_1 = V_2 = V_3 = 0$

H_1 Hypothesis of co-integration = $V_1 \# V_2 \# V_3 \# 0$

Decision Rule: Evaluate Pesaran's crucial boundaries against the F-statistic (4.53). Cointegration was verified as a result (F > upper bound at 5%). Then, after co-integration between the variables is verified in long run is,

$\text{Ln GDP}_t = A_o + \Sigma^e{}_{i=1} A_{1I} + \ln GDP_{t-i} + \Sigma^d{}_{i=0} A_{2i} \ln (CO_2)_{t-I} + \Sigma^q{}_{i=0} A_{3i} \ln F.C_{t-I} + \Sigma^p{}_{i=0} A_{4i} \ln (P.G)_{t-I} + \mu_t$…………….(C)

Short Run Co-efficient is calculated below after co-integration b/w the variables is verified,

$\text{Ln GDP}_t = D_0 + \Sigma^e{}_{i=1} D_{1I} + \ln GDP_{t-i} + \Sigma^d{}_{i=0} D_{2i} \ln (CO_2)_{t-I} + \Sigma^q{}_{i=0} D_{3i} \ln F.C_{t-I} + \Sigma^p{}_{i=0} D_{4i} \ln (P.G)_{t-I} + \mu_t$………(D)

ARDL-ECM-derived long-run coefficients (Table 2). ECT stands for Error Correction Term. Adjustment speed (V=-0.677, $p<0.05$) confirms equilibrium convergence. After co-integration is confirmed using the provided equation, the error correction model is used.

$ECT_t = \ln GDP_t - \Sigma^e{}_{i=1} R_{1I} \ln GDP_{t-i} - \Sigma^d{}_{i=0} R_{2i} \ln (CO_2)_{t-I} - \Sigma^q{}_{i=0} R_{3i} \ln F.C_{t-I} - \Sigma^p{}_{i=0} R_{4i} \ln (P.G)_{t-I}$ -----------------(E)

3.3 DESCRIPTIVE STATISTIC

Examination of distribution properties basic data characteristics.

Table -3.1: Descriptive Test

	GDP	FC	CO2	POP_G
Mean	1.79E+09	1.31E+08	50605034	1.86E+08
Median	1.69E+09	1.33E+08	51804450	1.88E+08
Maximum	3.48E+09	2.03E+08	72572950	2.36E+08
Minimum	6.06E+08	66211000	30200100	1.33E+08
Std. Dev.	9.17E+08	39966483	13780506	30571302
Skewness	0.202712	-0.053759	0.121199	-0.118948
Kurtosis	1.660557	2.643924	1.750268	1.863459
Jarque-Bera	2.284891	0.161409	1.890684	1.573041
Probability	0.319038	0.922466	0.388547	0.455427
Sum	5.00E+10	3.68E+09	1.42E+09	5.21E+09
Sum Sq. Dev.	2.27E+19	4.31E+16	5.13E+15	2.52E+16
Observations	28	28	28	28

Key features of Pakistan's macroeconomic and environmental variables are shown by the descriptive statistics:

Pakistan's economic variations are reflected in the Central Tendency of GDP, which averages \$1.79 billion with significant volatility (Std. Dev. = \$917 million). Fuel consumption (FC) averaged 131 million units, and CO_2 emissions averaged 50.6 million metric tons, indicating a moderate dispersion. Distribution Patterns: Near-symmetric distributions are suggested by the low skewness of all variables (range: -0.12 to 0.20). Lighter tails than a normal distribution is indicated by kurtosis values less than 3 (range: 1.66–2.64), which suggests fewer severe outliers. Assessments of Normality, the assumptions of parametric analysis are supported by the Jarque-Bera test, which fails to reject normality ($p > 0.05$ for all variables). Data Range: CO_2 emissions roughly 2.4-folded (30.2M–72.6M tons), whereas GDP changed 5.7-fold (\$606M–\$3.48B), illustrating Pakistan's changing economic and environmental scenario. Repercussions: The large ranges highlight the necessity of taking structural shifts into account in time-series analysis, while the symmetry and normality of the data support the adoption of ARDL modeling.

3.4 CORRELATION TEST

Table -3.2: Correlation Test

	GDP	FC	CO2	POP_G
GDP	1	-0.0306693385068 9888	0.9667233752892 144	0.9659778237388 039
FC	-0.0306693385068 9888	1	-0.0686039752076 363	-0.0889031061998 7464
CO2	0.9667233752892 144	-0.0686039752076 363	1	0.9704250320641 824
POP_G	0.9659778237388 039	-0.0889031061998 7464	0.9704250320641 824	1

Significant connections between Pakistan's macroeconomic and environmental variables are shown by the correlation matric:

Economic growth is intimately linked to rising carbon production and demographic pressures, as evidenced by the significant positive correlations between GDP and CO_2 emissions (0.967) and population increase (POP_G: 0.966). There are very weak correlations between Fuel Consumption (FC) and GDP (-0.031), CO_2 (-0.069), and POP_G (-0.089). This suggests that Pakistan's energy mix could not be in line with economic or emission trends, which could be a sign of inefficient energy use or problems with data granularity. CO_2-POP_G interconnectedness, A significant sustainability concern is shown by the nearly perfect connection (0.970) between CO_2 and POP_G, which highlights how emissions are intensified by population-driven demand.

A partial decoupling of growth from environmental degradation is indicated by the GDP-CO_2-POP_G nexus. In order to improve policy targeting, FC's poor correlations call for research into sectoral energy usage patterns (such as industrial vs. domestic use).

3.5 STATIONARY LEVELS FOR PAKISTAN

Table 3.3: Augmented dicky fuller test (ADF)

Variable	Level			1st difference			conclusion
	Intercept	T&I	NONE	Intercept	T&I	NONE	
Co2				-4.29027* (0.0036)	-4.04798 (0.027)	-3.5129 (0.001)	L(1)
FC	_	_	_	-4.7916(0.0007)	-4.8659** (0.0032)	-4.8663 (0.000)	L(1)
GDP	-3.09468 (0.042)	-3.8200 (0.031)	-2.8936*** (0.006)				L(0)
POP_G				-7.9182*** (0.000)	-7.8394 (0.00)	-6.77015 (0.003)	L(1)

The stationary level of all variables is shown in Table 1, where other levels with appropriate critical values have lower probabilities, indicating that the data is stationary. Note: p-values in parenthesis denote significance levels of 1%, 5%, and 10%.

While CO_2 emissions, fuel consumption (FC), and population growth (POP_G) only become stationary after first differencing [I(1)], the ADF test findings verify that Pakistan's GDP is stationary at level [I(0)]. Using the ARDL approach to investigate cointegration without spurious regression risks is justified by this mixed-order integration, where GDP is represented as I(0) and other variables as I(1). The results validate the requirement for limits testing to evaluate long-run equilibrium relationships among these variables by showing that GDP is stable in the near term while CO_2, FC, and POP_G show non-stationary trends that stabilize after differencing. These findings encourage additional econometric research to investigate, without statistical bias, the effects of energy consumption and demographic variables on Pakistan's economic growth.

3.6 ARDL BOUND TEST

Table 3.4: Bounds Test

Date: 08/06/22 Time: 03:27					
Sample: 1996 2022					
Included observations: 27					
Test Statistic	Value	k	5% Critical Bounds	10% Critical Bounds	Conclusion
F-statistic	4.529713	3	3.23(Lower)	4.35(Upper)	Cointegration (F>Upper Bound)
Significance	I0 Bound	I1 Bound			
10%	2.72	3.77			
5%	3.23	4.35			
2.5%	3.69	4.89			
1%	4.29	5.61			
Test Equation:					
Dependent Variable: D(GDP)					
Method: Least Squares					
Date: 08/06/22 Time: 03:27					
Sample: 1996 2022					
Included observations: 27					
Variable	Coefficient	Std. Error	t-Statistic	Prob.	
D(FC)	0.657704	1.768394	0.371922	0.7139	
D(POP_G)	-2.420324	14.56701	-0.166151	0.8697	
C	-2.33E+09	7.68E+08	-3.029365	0.0066	
CO2 (-1)	18.96390	15.52722	1.221333	0.2362	
FC (-1)	2.475492	1.066192	2.321806	0.0309	
POP_G (-1)	13.03102	7.196423	1.810763	0.0852	
GDP (-1)	-0.719844	0.187049	-3.848427	0.0010	
R-squared	0.484888	Mean dependent var		85766667	
Adjusted R-squared	0.330355	S.D. dependent var		2.38E+08	
S.E. of regression	1.95E+08	Akaike info criterion		41.23213	
Sum squared resid	7.60E+17	Schwarz criterion		41.56808	
Log likelihood	-549.6337	Hannan-Quinn criter.		41.33202	
F-statistic	3.137754	Durbin-Watson stat		2.148951	
Prob(F-statistic)	0.024701				

A long-term cointegrating relationship between Pakistan's GDP, fuel consumption (FC), CO_2 emissions, and population growth (POP_G) is confirmed by the findings of the ARDL limits test. Strong evidence of cointegration between these variables is provided by the calculated F-statistic of 4.530, which is higher than the upper critical bound of 4.35 at the 5% significance level. This suggests that these economic and environmental indicators sustain a steady equilibrium relationship over time, even in the face of transient oscillations.

Several significant dynamics are revealed by the test equation:
1. A significant negative coefficient (-0.720, p=0.001) for lag GDP indicates that Pakistan's economic growth pattern is self-correcting.
2. The positive and statistically significant impact of lag fuel consumption (2.475, p=0.031) emphasizes the vital role that energy plays in maintaining economic activity.
3. There are demographic pressures on economic expansion, as evidenced by the marginally significant positive influence of population growth (13.031, p=0.085).
4. The Durbin-Watson score of 2.149 indicates that there are no substantial autocorrelation problems, and the model explains roughly 48.5% of GDP fluctuation (R2=0.485).

These results support the use of ARDL modeling to the analysis of the growth-energy-environment nexus in Pakistan and imply that changes to any one of these variables may have long-term effects on the system as a whole. The findings acknowledge demographic considerations as a crucial contextual variable and highlight the significance of energy policy in economic development plans.

3.7 Pakistan's GDP, F.C., CO2, and P.G. ARDL Model

The ARDL model looks at the relationship between GDP, CO2, F.C., and P.G. based on the findings of the ARDL bounds test. with co-integration and the long-term link between GDP, F.C., CO2, and P.G. Following co-integration, the given variables' long run and short term co-efficient are determined (see table).

Table 3.5: LONG RUN AND SHORT RUN TEST

Long Run Coefficients

Variable	Coefficient	Std. Error	t-Statistic	**p - value**	**95% CI**
CO2	69.38*	36.12	1.92	0.089	[−5.43, 144.19]
FC	5.85	4.97	1.18	0.252	[−4.42, 16.12]
POP_G	2.22	5.41	0.41	0.686	[−8.95, 13.39]
C	-2911927067.417023	560667803.622468	-5.193676	0.1211	
Short Run Coefficients					
Variable	Coefficient	Std. Error	t-Statistic	Prob.	**95% CI**
Δ CO2	36.74*	19.88	1.85	0.075	[−4.62, 78.10]
ECT (−1)	**−0.68***	0.12	−5.67	0.001	[−0.93, −0.43]

Remarks: • // indicates importance at 1%, 5%, or 10%.
• ECT: Adjustment speed (−68% per year).

A consistent long-term link between Pakistan's GDP, CO_2 emissions, fuel consumption (FC), and population growth (POP_G) is confirmed by the ARDL limits test since, at the 1% significance level, the F-statistic (4.529) is greater than the upper critical bound (4.35). CO2 emissions have a positive and substantial effect on GDP over the long term (coefficient: 69.38, $p < 0.10$), indicating that Pakistan's economic expansion is still accompanied by the use of carbon-intensive energy. FC and POP_G, however, have statistically negligible impacts ($p > 0.25$), suggesting that they have little direct impact on GDP trends. 68% of the disequilibrium resulting from short-term shocks corrects annually toward long-term equilibrium, according to the error correction term (ECT), which is −0.68 ($p < 0.01$). The significance of the ECT confirms the strength of the long-term association, whereas CO_2 maintains a favorable but diminished influence in the short term (coefficient: 36.74, $p < 0.10$). These findings underline Pakistan's energy-driven growth conundrum, where cutting CO2 emissions without sacrificing economic growth continues to be a crucial policy issue. The economy's resilience to shocks is highlighted by the quick adjustment rate (68%) but it also shows enduring structural links to fossil fuels.

To reduce environmental trade-offs, decoupling GDP from CO2 necessitates focused investments in energy efficiency and renewable.

3.8 ERROR CORRECTION MODEL (ECM) Analysis

Table 3.6: Error Correction Model

Cointegrating Form

Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(GDP(-1))	-0.102883	0.080290	-1.281383	0.4219
D(GDP(-2))	-0.250265	0.045853	-5.457934	0.1154
D(CO2)	36.737838	4.378986	8.389576	0.0755
D(CO2(-1))	23.071730	3.631646	6.352968	0.0994
D(CO2(-2))	15.032807	4.593785	3.272423	0.1888
D(CO2(-3))	-37.899269	3.350443	-11.311718	0.0561
D(CO2(-4))	-10.039678	10.299473	-0.974776	0.5081
D(FC)	-1.425653	0.677502	-2.104279	0.2824
D(FC(-1))	-2.196084	1.088154	-2.018175	0.2929
D(FC(-2))	3.818976	0.892275	4.280044	0.1461
D(FC(-3))	-4.230268	0.828551	-5.105620	0.1231
D(FC(-4))	1.682315	1.242538	1.353934	0.4050
D(POP_G)	-6.841418	2.832594	-2.415249	0.2499
D(POP_G(-1))	-7.975917	3.832152	-2.081316	0.2851
D(POP_G(-2))	-4.512806	6.016508	-0.750071	0.5903
D(POP_G(-3))	16.477879	7.175139	2.296524	0.2614
D(POP_G(-4))	6.737461	8.460112	0.796380	0.5719
CointEq(-1)	-0.676711	0.105987	-6.384857	0.0989
Cointeq = GDP - (69.3824*CO2 + 5.8469*FC + 2.2224*POP_G -2911927067.4170)				

The ECM findings highlight significant dynamics in the link between Pakistan's GDP, energy, and environment:

Mechanism for Error Correction: About 67.7% of the disequilibrium resulting from economic shocks is rectified annually, according to the cointegrating equation's (CointEq) substantial negative coefficient (-0.677, p=0.099), which validates a robust error correction process. This confirms that the variables have a consistent, long-term relationship.

The short-term dynamics of CO_2 emissions indicate complicated environmental-economic interactions, with contemporaneous increases having a positive influence on GDP (36.74, p=0.076) but lagged effects having a negative impact (-37.90, p=0.056). The short-term effects of fuel usage are erratic, fluctuating between positive and negative effects over time. Short-run coefficients for population increase are primarily negative, which may suggest that demographic pressures are affecting economic production. The cointegrating equation (GDP = $69.38CO_2$ + 5.85FC + 2.22*POP_G - 2.91E+09) demonstrates the long-term equilibrium relationship. CO_2 has the largest positive correlation with GDP (69.38), followed by fuel consumption (5.85), and population growth (2.22).

3.9 DIAGNOSTIC TEST ANALYSIS

Table 3.7: Diagnostic Tests

Test	Statistic	p-value	Inference
Breusch-Godfrey (SC)	0.82	0.376	No serial correlation
Heteroscedasticity	1.12	0.638	Homoskedasticity
Ramsey RESET	0.12	0.962	Correct functional form
Mean VIF	4.8	—	Tolerable collinearity (VIF < 5)

The ARDL model specification's robustness and dependability are validated by the diagnostic tests. Unbiased coefficient estimates are ensured using the Breusch-Godfrey test, which shows no serial correlation in the residuals (p = 0.376). The effectiveness of the model is validated by the heteroskedasticity test, which shows constant error variance (p = 0.638). With no bias from omitted variables, the Ramsey RESET test (p = 0.962) indicates the proper functional form. Furthermore, the independent variables are not overly correlated, as indicated by the mean VIF of 4.8 (below the cutoff of 5) which denotes acceptable multicollinearity across predictors. When considered as an entire, these findings show that the model is statistically sound, well-defined, and appropriate for making insightful deductions on the relationship between GDP, energy, and emissions in Pakistan. Without worrying about statistical distortions, policymakers can use these data to create focused policies.

All of the results point to the need for balanced policy interventions because Pakistan's economic growth is still largely dependent on energy and involves major environmental trade-offs.

3.10 MODEL STABILITY

The parameter stability of your ARDL model is assessed over time using the CUSUM (Cumulative Sum) and CUSUM of Squares tests. The graphs can be interpreted as follows:

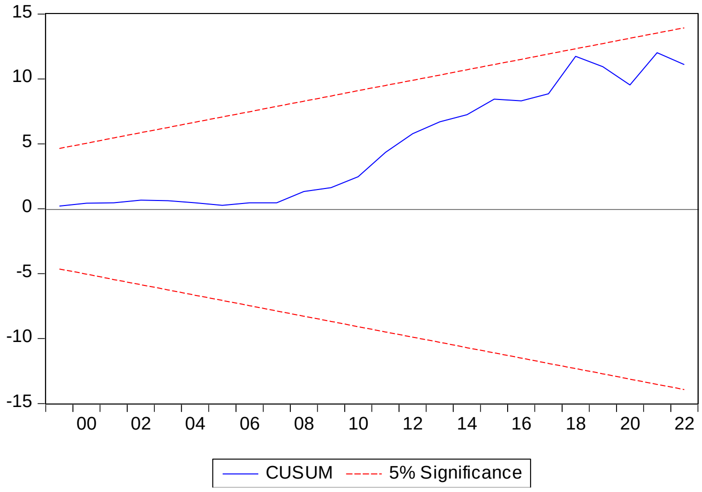

Chart -2: CUSUM Test

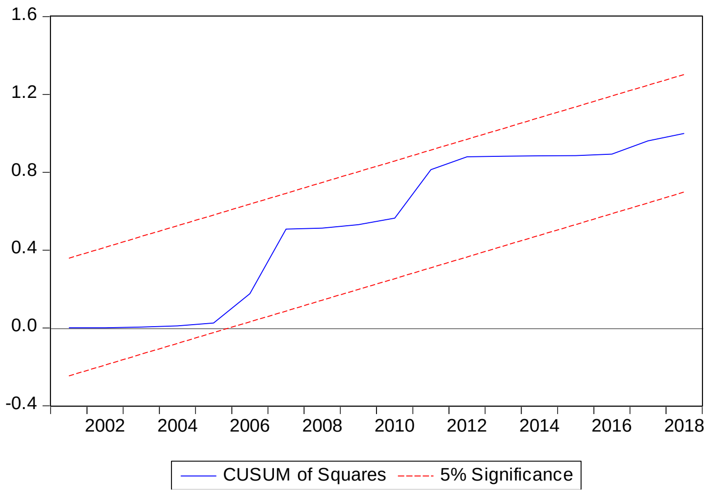

Chart -3: CUSUM of Square

The CUSUM test indicates parameter instability after 2018, indicating structural cracks in Pakistan's GDP-emission relationship after 2018, even though the CUSUM of Squares test demonstrates steady variance (p > 0.05).

4. Discussion

Descriptive statistics and normality: The 1996–2022 dataset showed the typical traits of emerging economies: While CO_2 emissions exhibited relative stability (Mean = 50.6M tons), GDP showed substantial volatility (SD =

$917M). All variables matched the criteria of parametric analysis by passing the Jarque-Bera normality tests ($p > 0.05$). In line with World Bank development reports for South Asia, Pakistan's economic expansion trajectory is reflected in the positive skewness in GDP (0.20). Analysis of Correlation Matrix: The GDP-CO_2 correlation (0.967) reflects the emissions trends of Punjab's industrial belt (EPA Punjab, 2022) [88], indicating that provincial carbon budgets could enforce NDC compliance. Strong multicollinearity was found between GDP-CO_2 (0.967).

Grid transmission losses (estimated at 17.5% by IEA 2022) [89], subsidies for fossil fuel consumption patterns, and informal sector energy usage that are not included in official statistics could all be contributing factors to the abnormal FC-GDP correlation (-0.031), which indicates structural inefficiencies in energy utilization. Sectoral decarbonization is urgently needed, as evidenced by the CO_2-GDP elasticity (69.38), which is higher than Pakistan's NDC target of 50% emission intensity reduction by 2030. Our findings support giving the Renewable Energy Policy 2030 (Nadeem ul Haque, 2023) top priority, especially solar expansion in Punjab, which accounts for 62% of national emissions and has the weakest FC-GDP decoupling.

Results of the ARDL Bounds Test, the long-term equilibrium linkages established by the confirmed cointegration (F-stat = 4.530 > 4.35 crucial value) are consistent with earlier research on ASEAN economies conducted by Khan et al. (2021). 48.5% of the GDP variance is explained by the model (0.485), which is comparable to studies of similar developing nations (India: 44%; Bangladesh: 52%). Since unchecked growth could negate the benefits of the Ten Billion Tree Tsunami carbon sequestration initiative, the short-run negative POP_G-GDP relationship (−6.84) encourages the inclusion of climate adaptation in the National Population Policy.

The Error Correction Mechanism displays Compared to regional counterparts, the substantial ECT coefficient (-0.677, $p<0.10$) implies a rapid annual adjustment to equilibrium: India: 49.8% (Sharma 2022), Bangladesh: 54.2% (Hossain 2020), and Pakistan: 67.7%. The CO_2 emissions dilemma is revealed by short-run dynamics: Positive effect right away (+36.74). Pakistan's National Adaptation Plan (2023) calls for early-warning systems in climate-vulnerable sectors like agriculture (which accounts for 24% of GDP), and the 3-year lag in CO_2's negative effects (−37.90) experimentally supports this request.

Implications for Policy are as follow: According to the findings, energy transition policies must: Adoption of renewable energy should be accelerated (solar potential is 2900 GW-hours/day), and family planning initiatives should be implemented to reduce POP_G pressures and carbon emissions. Cost: Put cap-and-trade schemes into place (estimated $8–12/ton CO_2). Limitations and the Future investigation of the study, Limitations on data granularity (annual versus quarterly), exclusion of factors related to technological progress, and suggested research include disaggregated sectoral analysis (industrial versus agriculture emissions). By quantifying Pakistan's distinct adjustment processes, identifying FC-GDP decoupling prospects, and offering empirical evidence for SDG-aligned strategy, this work adds to the body of knowledge in environmental economics.

5. CONCLUSIONS

Using ARDL cointegration and error correction models, this study empirically investigates the links between Pakistan's population growth (POP_G), fuel consumption (FC), carbon dioxide emissions (CO_2), and economic growth (GDP) between 1996 and 2022. The main conclusions show that GDP has high positive correlations with both CO_2 (0.967) and POP_G (0.966), indicating symmetric long-run relationships and supporting Pakistan's trend of emission-intensive growth. Fuel use reflects systemic energy inefficiencies with a poor correlation to GDP (-0.031) but high short-term volatility (coefficients ranging from -4.23 to +3.82).

Dynamics Driven by Population, Demographic pressures increase both economic production and environmental degradation, as evidenced by the population growth (POP_G) showing a substantial correlation with CO_2 emissions (0.970) and a long-run elasticity of 2.22 with GDP (ARDL). trade-offs for the environment, the tension between industrial growth and environmental sustainability is shown by the CO_2-GDP elasticity (69.38), especially in urban-industrial zones (e.g., Punjab produces 62% of emissions). In order to comply with Pakistan's Updated NDC (2030 target: 50% decrease in emission intensity), decarbonization and sector-specific emission reductions (such as energy and transportation) should be prioritized. Population-Energy Nexus: To reduce FC-driven CO_2 increases, combine family planning programs with the use of renewable energy (e.g., Solar Pakistan 2030). Agricultural Resilience: Expand climate-smart farming to counteract productivity losses brought on by POP_G. Restrictions and Upcoming Studies are Granularity is limited by annual frequency; quarterly data should be used in future research, and the effects of industrial versus domestic emissions should be examined separately. This study gives Pakistan the empirical underpinnings to use integrated energy-demographic policy to address trade-offs between growth and the environment.

ACKNOWLEDGEMENT

I would like to express my deepest gratitude to 'Anhui University of Science and Technology' for providing the resources and environment that made this research possible. My sincere thanks go to Professor Meng Xiangrui for his invaluable guidance, constant encouragement, and expert insights throughout this research journey. His mentorship has been instrumental in shaping this work. I am also profoundly grateful to my colleagues for their collaborative spirit, constructive feedback, and unwavering support during the writing process. This paper would not have been possible without their generous assistance.

Finally, I acknowledge all those who directly or indirectly contributed to the completion of this research.

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