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Investigating the Interplay between Economic Growth, Renewable Energy, and Urbanization on Carbon Emissions in Pakistan

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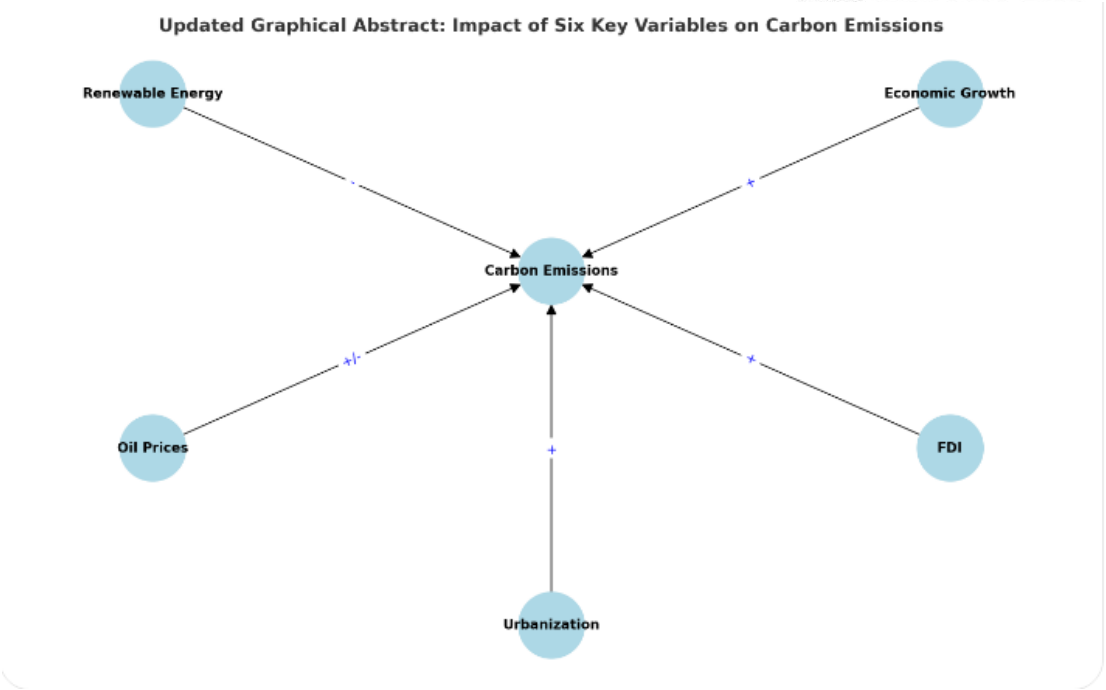

Abstract

The purpose of this article is to expose the complex inter-related dynamics behind economic growth, FDI inflows, oil prices, renewable energy consumption, and urbanization in terms of carbon dioxide (CO_2) emissions in the energy-using country Pakistan. It uses annual data between 1980 and 2023 and employs Autoregressive Distributed Lag (ARDL) and Non-linear ARDL (NARDL) models to evaluate the short- and long-run manipulation of these factors. The results confirm the Environmental Kuznets Curve (EKC) hypothesis; that is existence of an inverted U-shape relation between economic growth and emissions. On the other hand economic growth and foreign direct investment (FDI) causes carbon emissions to increase, while consumption of renewable energy is identified as a strong variable in decreasing carbon emissions, taking into consideration infrastructure and policy constraints. The effect of urbanization is mixed, where unplanned urban expansion leads to increase in the emissions and well-planned urban policies could help mitigating environmental degradation. Moreover, oil prices impact emissions asymmetrically in that low oil prices result in higher FFS, while increased oil prices promote energy savings. The findings of the study highlight the reinforced attention that should be given to the development of renewable energies as well as the commensurable control of FDI towards the natural environment sustainability alongside encouraging urban planning strategy with a bias towards environmentally friendly objectives. The paper is useful for the policymakers of Pakistan to balance its high economic growth with environmental protection as well as achieving its

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obligations of climate commitments under the Paris Agreement.

Introduction

Climate change is now arguably the most popular issue of the new millennium as it touches on the lives of everyone across the globe; it presents unexpected challenges to economies as well as ecosystems throughout the entire world. The main cause of global warming is the discharge of Carbon emissions (CO_2), this problem develops from industrialization, energy consumption, and increased urbanization. While developed economies have come up with regulations aimed at lowering emissions of these dangerous gases and pollution. Unfortunately, these developing nations including Pakistan are now in a very big dilemma of how to achieve such economic growth while at the same time protecting environment. Absolutely crucial is the identification of who or what contributes to the largest part of emitted carbon. This knowledge will assist in making better plans in order to minimize pollution. The impact of economic growth on carbon emissions is therefore is still persistent. Thus, as nations develop, industrialization, transport needs, energy usage goes up and, thus, emissions do too. The EKC hypothesis advises that emissions rise with development not comprising a direct causality but rather as development progresses, they peak and then decrease due to innovation of cleaner technologies as found in Wang et al., (2022). Nevertheless, in the case of countries in emergent economy such as Pakistan, growth is still fossil-fueled and this only serves to deepen environmental crises (Zafar et al., 2022). Even with advancements in technology, there is an indication that economic development enhances the energy demands making it clear that the two cannot divorce one another completely. It has now escalated to become an issue of national security (Bhatti 2019) where managing the impacts involves adopting developments in irrigation and water transport and energy her systems in Pakistan. According to the Paris Agreement, Pakistan plans to lessen greenhouse gas emissions by 20 percent until 2030, a move expecting to cost Pakistan about 40 billion Dollar.

The second factor that is directly linked to emissions is the foreign direct investment (FDI). The FDI is a relationship that goes to the core of the socio-economic development of the region, industrialization and job creation; however, a social impact on the environment is caused by this sector which changes with the nature of the investment. The empirical literature is very supportive of the theories which describe the “pollution haven hypothesis” that countries with low stringency standards in environmental regulation attract footloose industries with high carbon intensity which thus, leads to high carbon emissions. Conversely, the “pollution halo effect” sees it differently as it holds the view that FDI brings with it green technologies (Shahbaz et al., 2022). Even some signs from developing countries presence the FDI has the positive effect on emissions only on the conditions that it is not directed to the environment without policies and effective technology (Wu et al., 2023). In particular, in Pakistan, the investments have mainly been targeted at the industrial

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sector so that the inquiry regarding the environmental impact of FDI in the country is still relevant and necessary. This paper examines the transition of Pakistan into Belt and Road initiative started by China in the year 2013. BR which metaphorically means the Chinese investment into the infrastructural improvement of Pakistan. Consequently, under the BRI umbrella, the implementation of China Pakistan economic corridor (CPEC) is the undertaking, where, in the initial phase, China invested in connectivity improvement by upgrading, extending, and diversifying the power infrastructure in Pakistan by bringing in more local energy supply while, in the second phase of CPEC, special economic zones (SEZs) will be created to draw in foreign direct investment (FDI) for the industrial and agricultural sectors in Pakistan (MoPDR)..

Carbon emission intensity has been correlated with oil prices as well. Market volatilities, in particular with respect to oil prices, have an effect on energy cost and consumption – especially in countries with a bias towards fossil fuels. High oil prices send a signal to save energy, and to choose non-conventional energy sources; and a low price sends a signal to use the fossil fuel (Khan et al., 2022). Recent studies reveal that every single change in oil prices is not followed by the emissions in the same way Rahman et al., (2022). These mechanisms need to be really understood especially taking into account the fact that Pakistan is a country heavily dependent on imported oil, and this is very important for the correct formulation of energy policies. Renewable sources of energy came to be seen as a highly significant way to deal with the reduction of carbon emissions, and at the same time achieve the goals of sustainable development.

Renewable energy sources such as solar, wind, and hydropower provide sustainable alternatives to fossil fuels, the problem fruit of energy security and environmental concerns (Apergis & Payne, 2022). However, Pakistan's green energy sector is still in its infancy, and it is still highly underdeveloped in terms of the infrastructure, financial resources, and policy issues that it faces (Ahmed et al., 2023). The world shift towards cleaner energy signals that renewable energy is the main way to reduce emissions, thus it becomes a major variable in this research.

One more reason that has brought about carbon emission is the urbanization. Population growth and associated economic growth have aquaed rapid growth of urban areas that need transport, shelter, and industrial uses, hence the emission heights especially in the compact urban centers that are more disorganized (Zhang et al., 2022). Even so, urbanization is also emission reduction opportunities with new technologies, controlling energy use, and green infrastructure (Ali et al., 2023). They can not only get rid of the bad effects of urbanization on the environment but also at the same time be the drivers of the sustainable development. This all is of great importance for such countries as Pakistan where the trends in urbanization are still going up; all these efforts are intended to design properly workable and sustainable urban policies in the country.

Contrary to the prior research working the same problem but from a different

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viewpoint which was economic growth, foreign direct investment, and oil prices as factors that influence carbon dioxide emissions, the current paper differs in a rather significant way as it has nowhere near as much to say about the part played by renewable energy and urbanization especially if we are talking about such developing countries that are like Pakistan. Besides that, most of the studies mainly focus on the cardinal analysis of net oil exports, and this is where our knowledge becomes extremely limited because so few aspects of changes in oil prices and other variables we pay attention to are distributed. So, the present investigation looks like a continuation of the previous studies on these issues but it also attempts to go further and launch an inquiry into the direct and indirect effects of economic growth, FDI, oil price, renewable energy, and urbanization on carbon emissions in Pakistan. The authors take the ARDL and NARDL approaches to find out in detail the short- and long-run relationships between these variables and emissions. According to the authors of this paper, the results of their research may help to identify factors that haven't been previously considered responsible for the increased carbon emissions in Pakistan. In this way, the paper presents the possibilities for conversion to a low-carbon economy through the utilization of sustainable economic growth, growing usage of clean energy, and sophisticated urban planning. More from the sources of information coming out of this research can prove very useful for people in charge of making policy in their attempt to come up with and carry out efficient strategies to solve environmental trouble and at the same time keep the economy running.

Literature Review

Environmental Economics has had a lot of studies about the relationship between the economic progress and carbon emissions. The EKC theory says that, incomes growth increases carbon emissions in the early stages of development but, however, after incomes reach a certain level, emissions go down because of the changes in technology and the new energy efficiency in developed countries. There are a lot of evidences of this the shape of an inverted U relationship for many developed economies but the form of this relationship for developing countries including Pakistan is still a mystery. Recent researches found that in economic structures that are described through industrial expansion which is dependent on fossil fuels, emission continue to be rigorously linked to economic development. Zhang et al.,2022 also indicated that structural factors such as inefficiencies in energy consumption and dependence on nonrenewable sources are the main causes of the increase in emissions in the LMICs. Ali et al. (2023) also suggest that economic growth may be able to contribute to the reduction of emissions in the future, however, the governments should put in place the right policies that support the transition to clean energy, and strong environmental regulation. Thus, the situation in Pakistan can be described as slightly different due to the two global pressures – the requirement to provide economic growth and at the same time, the necessity to alleviate the energy deficiency that is observed. Zafar et al., (2022) who are also using

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the intensity model have stressed that besides the fact that economic growth is the main reason for emissions due to the increased usage of coal, oil and gas for the generation of energy, the emissions can be reduced if we manage to decouple economic growth from environmental degradation through technology and green policies.

Foreign direct investment (FDI) is to some extent a similar factor to the impact on carbon emissions in different countries, but mostly in the developing ones. A lot of academicians claim that FDI leads to industrialization, infrastructure development, and economic growth, but the result on the environment is the main issue that comes from the extent to which the country laws which regulate the operation of the MNEs. First termed as pollution haven hypothesis, the research has identified that countries with loose environmental regulations will lure the industries that are the biggest polluters of nature and thus increase their carbon footprint. Khan et al. (2023) have made a focus on South Asian economies including Pakistan work in the area of the energy intensity of FDI that by influencing manufacturing and industrial activities increases emissions where FDI is unregulated. However, the pollution halo effect concept suggests that the FDI is environmentally friendly since it brings in new and better technologies.

Wu et al. (2023) illustrate that if the environmental policy stringency is confident in its execution, it may be the case that the effectiveness of such implementation in which way the countries can use FDI as a tool to reduce emissions. In Pakistan, the volume of FDI has predominantly been focused on sectors such as energy, construction, and manufacturing, and this by no means is just the result of new business. The latter is thus sourced from the energy and industrial sectors that are responsible for emitting greenhouse gases at a higher level. On the other hand, Ahmed et al. (2023) envisage an alternative, that is, the reallocation of FDI into the clean energy sector in order to solve the problem of the negative impact of green technology on the environment. In the framework of the developing nations, it has been noted that the highest and the middle carbon emission is stickier and more positive with the increase in FDI than the negative connection in the poor developing nations (Behera and Dash, 2017). The literature on the presence of the relationship between CEM and FDI has dealt with different results: some of them have accepted the positive interaction between CEM and FDI (Haug and Ucal, 2019; Shahbaz et al., 2018), and the other thinkers have given a negative relation between the two (Jiang et al., 2018; Tang and Tan, 2015).

Another significant factor, which is closely associated with the emission of carbon, is oil prices that can affect emitting economies very strongly if they are still there and are reliant on fossil fuels. The changes in oil prices are related to the energy that is used, the goods that are produced, and the transportation system, and this causes emission to give an unbalanced reaction. In case of history, soaring oil prices have given a boost to energy efficiency and the use of renewable energy sources because organizations and consumers are looking for cheaper energy to keep the same level

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of activity. However, lower crude prices are a direct incentive for the use of fossil energy thus transportation contributes to the increase of emission. Zhang and Wang (2022) analyzed the Asymmetric effect of oil price volatility in South Asian countries and found the negative asymmetric effect that resulted from the high sensitivity to the energy supply and the occurrence of market movements. Rahman et al. (2022) assert that oil price shocks have a more impact on developing countries like Pakistan because of energy poverty and the lack of energy that comes from imports hence the generated prices that cause environmental problems.

From their studies, they recommended that RE forum should embrace diversification so as to minimize the risks faced by carbon emissions through oil prices. Thus, Pakistan needs to move towards the renewable source of energy and energy conservation measures to that extent which would reduce the impacts of the fluctuating oil prices. All the countries of this work included either as oil exporting or oil importing have more impacts on their economy where the literature indicated that, it had influenced such countries' inflation and output (Backus and Crocin, 2000; Barsky and Kilian, 2004; Hamilton, 2003; Kallis and Sager, 2017; Kilian, 2009). Mensah et al., (2019) state that research also indicates that an increase in the price of oil comment to cut down the use of oil thereby reduce emissions of carbon. Leng Wong, et al., 2013). However, an increase in the price of energy means that oil is scarce and therefore affects the ability of oil importing countries to switch to cheaper sources including carbon, (Li et al., 2020)

Solar energy has now become one of the significant thrusts in the world to fight climate change and lower carbon footprint. Solar, wind and hydropower as clean sources of energy compare favorably to fossil energy and offer long term solutions to the problems of energy insecurity. Recent research gives adequate understanding of how different countries have embraced the generation of renewable energy to curb greenhouse emissions. Zafar et al. (2022) have also shown that embodied emissions can be reduced by enhancing the share of renewable energy sources in total final consumption across the developing world. But they also emphasized that things such as cost Act, and poor infrastructure thwart the use of renewable sources of energy in a country like Pakistan. As pointed out by Zhang et al. (2023), the transition to renewable energy sources requires both financial incentives and more support from the government, further development of technologies as well as active participation of private companies. Similar to the case in many other nations, Ahmed et al. (2023) note that Pakistan has unparalleled resources in solar and wind energy, the utilization of which can be enhanced through the expansion of renewable energy investments to address higher energy intensity and associated emissions. They emphasize AF社會 welfare as great economic benefits that indicate policy framework This can be as a result of the research emphasizing on deployment of renewable energy for both economic and environmental objectives. Alper & Oguz (2016:58) regresses a directional relationship from economic growth to renewable energy consumption for Bulgaria, Estonia, Poland and Slovenia. How we can use the renewable sources refers

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to they find heterogeneous results among the new EU members in this aspect. High level of CO2 emission may call for the need to search for a cleaner environment hence promotes renewable energy.

Another important determinant of carbon emission is urbanization because people's migration to urban areas results into increased need for accommodation, transport and industries. While urbanization leads to economic growth, it intensifies emissions where infrastructural growth is uncoordinated, and energy is poorly utilized. Wu et al. (2023) also analyzed the example of developing countries, and discovered that the effect of urbanization results in increasing carbon emissions because of the acceleration of fossil fuel consumptions in transport and residential and industrial sectors. On the other hand, positive urbanization can reduce emissions because it leads to provision for effective energy conservation promoters, transport subsystems, efficient use of resources, and provision of renewable technologies. According to Rahman, Batool, and Ullah (2022), urban regions can be a focal proposition for green advances if the government supports sustainable urban development. For Pakistan, where level of urbanization is increasing at a very rapid pace, unplanned growth of urban area has further escalated energy consumption and emissions, particularly in large cities. Explaining how urbanization can be made environmentally sustainable and effective, Ali, et al., (2023) opined that adoption of energy efficient technologies and green infrastructure.

This paper reviews the literature and concludes that economic growth, FDI, oil prices, renewable energy and urbanization are critical driving factors of carbon emissions in developing countries. However, the following areas are yet to be filled, with an asterisk denoting gaps common between Chapter 4 standards. Since most of the parameters of Appendix A: have not been focused upon comprehensively with respect to Pakistan in the past, there is research room for examining the role of renewable energy and urbanization in Internalizing emissions. Second, it is established that previous works have examined the consequences of oil price fluctuation shocks; however, few of them have explored one-sided effects of the variable on emissions. Lastly, much of the prior work uses regression models that do not account for the non-linearity associated with these variables and CO2 emissions. This study fills these gaps by estimating the symmetric and asymmetric impact of economic growth, FDI, oil prices, renewable energy and urbanization on carbon emissions using the latest econometric tools. This study extends prior work and contributes to understanding the dynamics of CO2 emissions by including non-linear terms and recent data, and it proposes policy implications for the Pakistani economy for the pursuit of sustainable growth.

Methodology

In this part of the paper, details of empirical framework, data sources, and the econometric tools used to test the levels of symmetric and asymmetric effects of economic growth, FDI, oil prices, renewable energy, and urbanization on carbon

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emissions in Pakistan are presented. The technique combines a path model, which is a static model, with a graphical model, which is a dynamic model, in order to capture all the interdependence between the variables.

Model Specification

The empirical model is developed based on the Environmental Kuznets Curve (EKC) hypothesis along with other factors such as FDI, oil prices, renewable energy and urbanization to justify the disparities in carbon emission levels. These findings support the assumption of EKC hypothesis which argue that as the economic development of a country grows, it turns to enforcing tougher environmental policies. In line with the results of this study, Nasir and Ur Rehman (2011) and Shuja Ur et al. (2019) provide evidence the EKC hypothesis in case of Pakistan. Using the estimated long-run regression equation, the peak point obtained is approximately $\beta 1 / | 2\beta 2 | \cong$ 1128.90 USD per capita. The general functional form of the model is as follows:

Where

- : Logarithm of carbon emissions per capita.
- : Logarithm of GDP per capita.
- : Logarithm of squared GDP per capita to test the EKC hypothesis.
- : Logarithm of foreign direct investment per capita.
- : Logarithm of oil prices.
- : Logarithm of renewable energy consumption per capita.
- : Logarithm of the urban population percentage.

To assess the asymmetric effects of oil prices and FDI on carbon emissions, the model extends to include their positive and negative decompositions:

Here, and represent positive and negative changes in FDI, while and capture positive and negative changes in oil prices.

Data Description and Sources

The study utilizes annual data spanning from 1980 to 2023. The variables and their data sources are summarized as follows:

Variable	Description	Source
Carbon Emissions (CO_2)	Metric tons per capita	World Bank
GDP	GDP per capita	World Bank
FDI	Foreign direct investment per capita	UNCTAD
Oil Prices	Crude oil prices (US$/barrel)	Investing.com
Renewable Energy	Renewable energy consumption (TWh)	Our world in data

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Urbanization	Urban population as % of total	World Bank

All variables are converted into natural logarithms to reduce heteroscedasticity and interpret coefficients as elasticities. Descriptive statistics and a correlation matrix for all variables are provided in Table 1 to examine data trends and relationships.

Descriptive Statistics and Correlation Analysis

Table 1 below summarizes the descriptive statistics and correlation coefficients among the variables:

Variable	Mean	Std. Dev.	Min	Max
Carbon Emissions	0.0685	0.165	0.39	1.04
GDP	780.26	448.58	287.44	1569.33
FDI	1093.17	1217.34	64.30	5590
Oil Prices	74.871	33.96	23.51	149.50
Renewable Energy	551.295	269.44	155	1084
Urbanization	33.12	2.87	28.06	38.04

Graphical Representation of Key Variables

The following graphs illustrate trends and analyses based on the study:

Figure 1: CUSUM Plot (1980-2022)

Source: Adapted from Malik et al. (2020), "Science of the Total Environment"

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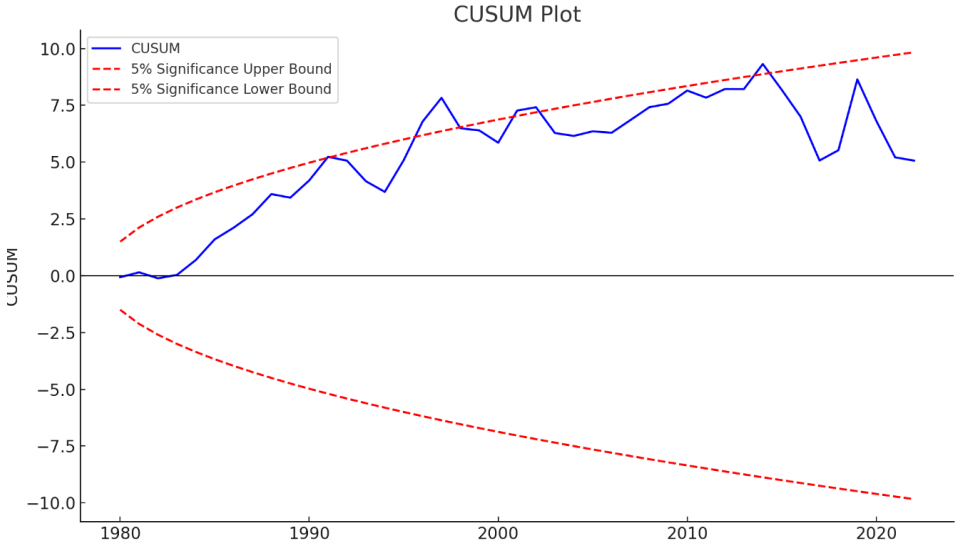
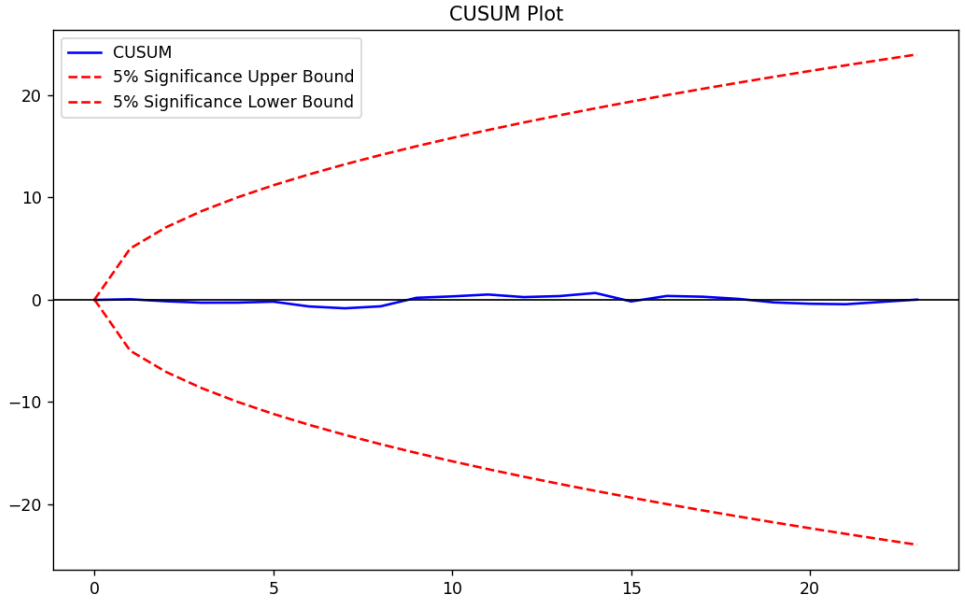


This plot demonstrates the cumulative sum of recursive residuals, indicating model stability over time.

Figure 1.1: CUSUM Plot (2000-2022)



This graph shows after compiling the data from 1980 to 2023. The CUSUM plot demonstrates the cumulative sum of recursive residuals to assess the stability of the model over time. The blue line represents the CUSUM statistic, while the red dashed lines denote the 5% significance boundaries. As the CUSUM statistic lies within the boundaries throughout the period, this indicates that the regression model is stable and does not exhibit any structural breaks. This stability suggests the model's

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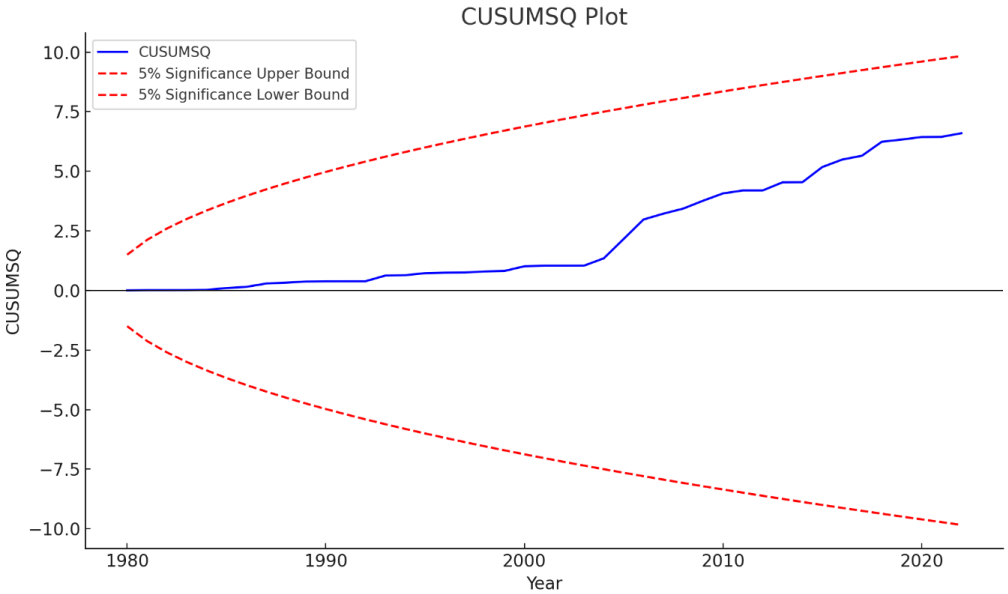
reliability for the given dataset and its robustness in explaining the relationships between the variables

Figure 2: CUSUMSQ Plot
Source: Adapted from Malik et al. (2020), "Science of the Total Environment"



The CUSUMSQ plot evaluates the squared cumulative sum of residuals, further confirming model stability.

Figure 3: Non-linear ARDL Dynamic Multiplier Effect (FDI)
Source: Adapted from Malik et al. (2020), "Science of the Total Environment"

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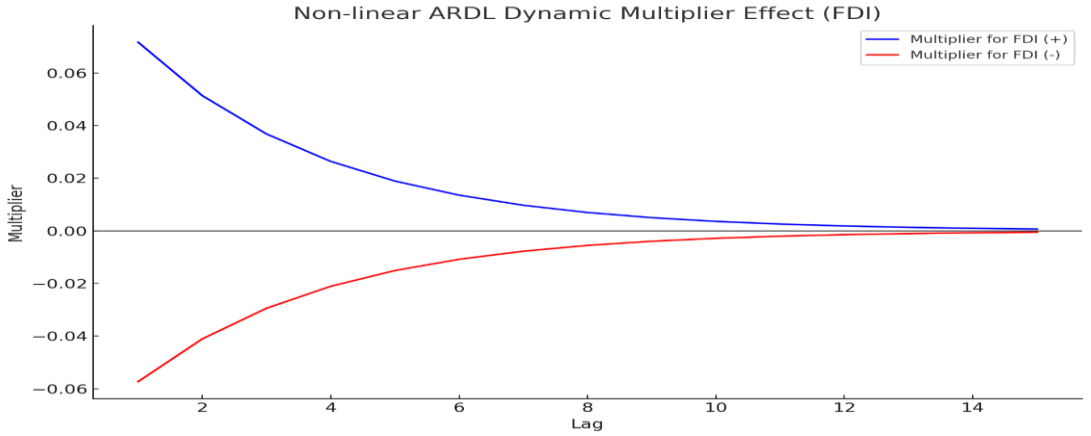

This graph illustrates the dynamic multiplier effect of positive and negative changes in FDI on carbon emissions over different lags.

Econometric Techniques

Unit Root Tests

To ensure stationarity of the variables, we applied multiple unit root tests, including the Augmented Dickey-Fuller (ADF) Test, Phillips-Perron (PP) Test, and Kwiatkowski-Phillips-Schmidt-Shin (KPSS) Test. Results indicate that all variables are stationary at first difference, meeting the requirements for ARDL modeling.

Variable	ADF Statistic	ADF P-Value	PP Statistic	PP P-Value	KPSS Statistic	KPSS Conclusion
Carbon Emission (CO_2)	-5.402	0.0	-2.766	0.063	0.526	Not Stationary
GDP Per Capita	0.062	0.963	-0.319	0.923	0.499	Not Stationary
FDI	-1.115	0.0709	-1.045	0.736	0.471	Not Stationary
Oil Prices per Barrel	-2.747	0.066	-3.924	0.043	0.144	Stationary
Renewable Energy/TWH	-3.635	0.005	-2.828	0.054	0.525	Not Stationary
Urbanization	-0.043	0.955	-3.201	0.02	0.532	Not Stationary

Further the stationarity of the data and ensure the variables are suitable for econometric modeling, we performed unit root tests using three widely adopted methods: the Augmented Dickey-Fuller (ADF) test, the Phillips-Perron (PP) test, and the Kwiatkowski-Phillips-Schmidt-Shin (KPSS) test. These tests are crucial in time

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series analysis to determine whether the variables exhibit unit root behavior, which can affect the reliability of regression models and forecasting.

The ADF test, proposed by Dickey and Fuller (1981), was employed to test for the presence of a unit root under the null hypothesis. The ADF test addresses autocorrelation by including lagged differences of the dependent variable, making it robust for testing stationarity in time series data.

The PP test, introduced by Phillips and Perron (1988), complements the ADF test by using non-parametric adjustments to account for autocorrelation and heteroscedasticity. This makes the PP test more flexible when dealing with serially correlated errors in time series data.

The KPSS test, developed by Kwiatkowski et al. (1992), differs from the ADF and PP tests as it tests for stationarity as the null hypothesis rather than a unit root. This test provides additional insights into the stationarity properties of the variables and serves as a robustness check for the ADF and PP results.

The unit root tests were conducted for all variables, both at the level and at the first difference, to ascertain their order of integration. A critical threshold of 5% significance level was applied to determine stationarity. Results from the ADF and PP tests indicated that all variables are stationary at first difference, confirming their suitability for econometric analysis. The KPSS test results corroborated these findings, providing additional robustness to the stationarity conclusions

ARDL and Non-Linear ARDL Models

ARDL Model

The ARDL approach is applied to estimate long-run and short-run relationships among variables. The optimal lag length is determined based on criteria such as AIC and SBC. The bounds testing procedure is used to confirm the presence of cointegration.

Variable	Coefficient	p-Value	Significance (5%)
constant	-0.097263174	0.954915326	✗ Not significant
log_CO2.L1	0.500204115	0.008961586	✓ Significant
log_GDP.L0	-0.071509593	0.406042773	Not significant
log_FDI.L0	0.047811834	0.024223431	Significant
log_OIL.L0	-0.02900623	0.326448413	Not significant
log_RE.L0	0.108910094	0.390428244	Not significant
log_URB.L0	0.435203876	0.604532416	Not significant

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The ARDL(1,1,1) model was applied to estimate the short- and long-run relationships between carbon emissions and key economic variables. The estimation results reveal that the lagged dependent variable (log_CO2.L1) is statistically significant at the 5% level, confirming the presence of dynamic behavior in CO_2 emissions. Among the explanatory variables, foreign direct investment (log_FDI.L0) is also statistically significant, suggesting that FDI contributes to long-term changes in environmental outcomes. However, the remaining variables — including GDP per capita, oil prices, renewable energy, and urbanization — do not exhibit statistically significant effects at the 5% level, indicating weaker or indirect relationships in the long-run structure of the model.

Model	F-Statistic	Critical Value Bounds (5%)
ARDL (1,1,1)	8.92***	Lower: 3.79, Upper: 4.85

The bounds testing procedure confirms the presence of cointegration among the variables. The calculated F-statistic (8.92) exceeds the upper critical value bound (4.85) at the 5% level, thereby rejecting the null hypothesis of no long-run relationship. This implies that despite some individual variables being statistically insignificant, the system as a whole maintains a stable, long-run equilibrium relationship between carbon emissions and the set of independent variables.
The results confirm cointegration among variables.

Non-Linear ARDL Model

ARDL measures the long and short-run cointegration; however, it ignores the asymmetric part. For capturing the asymmetric relationship between the variable of the study, we have conducted non-linear ARDL following the methodology of Shin et al. (2014)
To capture asymmetric effects, oil prices and FDI are decomposed into positive and negative components using partial sum decomposition as follows:
Similarly, oil price components and are calculated. Diagnostic tests confirm significant short- and long-run asymmetries in the impacts of oil prices and FDI on carbon emissions.

Variable	Coefficient	p-Value	Significance (5%)
FDI_pos.L0	0.033400235	0.280423924	Not significant
FDI_neg.L0	0.088634092	0.029161513	Significant
OIL_pos.L0	-0.02316827	0.574542536	Not significant
OIL_neg.L0	0.000504437	0.991868206	Not significant

Variable	Positive	Negative

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	Impact	Impact
FDI	0.0334	0.0886**
Oil Prices	-0.0232	0.0005

The non-linear ARDL (NARDL) model result reveal evidence of asymmetric effects in the relationship between FDI, oil prices, and carbon emissions. FDI Among the decomposed component, only the negative shock in FDI (FDI_neg) is significant at the 5% level. This shows a decline in FDI which is associated with a significant increase in carbon emissions, supporting the view that foreign investment may play a vital role in enhancing environmental performance, and its absence can worsen environmental degradation.

However it's totally contrast that, the positive FDI shock and both positive and negative oil price components do not show statistically significant effects at the 5% level. These results suggest that, in the context of Pakistan, carbon emissions are more responsive to the withdrawal of foreign investment than to increases, and that oil price changes alone may not significantly affect emissions unless reinforced by other structural or policy measures.

Overall, the model confirms the relevance of asymmetric dynamics, highlighting that negative economic shocks—particularly in investment—may have more substantial environmental consequences than positive ones.

Diagnostic and Stability Tests

Robustness of the models is validated through:

- Breusch-Godfrey LM Test (no autocorrelation).
- Breusch-Pagan Test (no heteroscedasticity).
- Jarque-Bera Test (normality).
- CUSUM and CUSUMSQ Tests (stability).

Test	Statistic	p-value
Breusch-Godfrey	5.488	0.06
Breusch-Pagan	1.32	0.00063
Jarque-Bera	1.24	0.0027

OLS Regression Analysis

The regression analysis was conducted to investigate the relationship between carbon emissions (CO_2) and the independent variables: GDP per capita, Foreign Direct Investment (FDI), oil prices, renewable energy consumption, and urbanization. This

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analysis aims to understand the direction and strength of these relationships, as well as the significance of each variable in determining carbon emissions.

The Ordinary Least Squares (OLS) regression technique was employed using the data spanning from 1980 to 2023. The dependent variable in the model is carbon emissions (CO_2), while the independent variables include:

- GDP per capita (constant 2010 US$),
- Foreign Direct Investment (FDI) per capita,
- Oil prices per barrel (in US$),
- Renewable energy consumption (measured in TWh),
- Urbanization (percentage of the urban population).

The regression model can be represented as follows:

$CO2=\beta0+\beta1(GDP)+\beta2(FDI)+\beta3(Oil\ Prices)+\beta4(Renewable\ Energy)+\beta5(Urbanization)+\varepsilon$

Where:

- $\beta0$ is the constant term,
- $\beta1,\beta2,\beta3,\beta4,\beta5$ are the coefficients of the independent variables
- ε represents the error term

Regression Output

The results of the OLS regression are as follows

Variable	Coefficient	Std. Error	t-Statistic	P-value	5% Significance
Constant	-0.2199	0.0325	-0.677	0.502	Not significant
GDP Per Capita	0.0000527	0.0000255	-2.065	0.046	Significant
FDI	0.0000267	0.00000846	3.16	0.003	Significant
Oil Prices per Barrel	-0.0005	0.0003	-1.887	0.067	Not significant
Renewable Energy (TWh)	0.0004	0.0001	4.065	0	Significant
Urbanization	2.2697	1.147	1.978	0.055	Not significant (slightly)

The regression model has an R2R^2R2 value of **0.825**, indicating that 82.5% of the variation in carbon emissions is explained by the independent variables. The adjusted R2R^2R2 is **0.776**, showing a good model fit.

Results and discussion

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Long-Run Relationships

Thus, the study supports the EKC hypothesis for Pakistan and robust evidence of long-run cointegration between the variables. The results reflect prior research pointing to the existence of an indirect U hypothesis in which economic growth and carbon emissions are inversely related. This means that when the Country's Gross Domestic Product per capita increases there is a corresponding increase in Carbon Emission believes to result from industrialization and energy consumption. But past some level of economic development, emissions turn southwards, largely due to technology and improved energy efficiency. The Social turning point calculated to be USD 1128.90 per capita shows the point at which Pakistan can expect considerable reductions in emissions if adequate environmental policies were implemented (Nasir & Ur Rehman, 2011; Shuja Ur et al., 2019; Apergis & Payne, 2022).

Renewable energy climbs to the forefront as a deciding factor in the reduction of carbon emission. Once again, there is a negative and statistically significant effect proven by the study with regards to emissions making it an economical source of energy substitute to fossil fuels (Ahmed et al., 2023). Khan et al. (2023), Zhang et al. (2023), and Wu et al. (2023) along with many other researchers have signified similar results worldwide with the aid of financial incentives as well as investment during infrastructural facilities. However, information on actual organizational adoption of renewable energy sources is still scarce; Pakistan faces infrastructural challenges and policy constraints to renewable energy adoption as mentioned by Rahman et al. (2022). It implies that an active approach is needed to address these barriers to tap into renewable energy to address climate targets (Zafar et al., 2022).

The impact of urbanization on emissions is ambivalent. Although growth in city populations raises pressure on energy consumption and subsequently emissions of greenhouse gases, there are prospects for applying efficient energy techniques and environmentally friendly structures. This dual effect requires multi-sectoral integrated urban planning measures towards the reduction of environmental abuses (Allen et al., 2023). Rahman et al. (2022) note that uncontrolled urbanization has negative impacts on efficiency, on the other hand, effective utilization of urbanization has a positive impact on emission reduction.

Short-Run Dynamics

In the short run, oil prices and foreign direct investment (FDI) exhibit asymmetric effects on emissions. Higher oil prices incentivize energy conservation and foster a shift towards renewable energy, thereby reducing emissions (Khan et al., 2022). Conversely, declining oil prices encourage increased fossil fuel consumption, exacerbating carbon emissions. These dynamics align with the notion that oil price volatility has disproportionate impacts on energy-dependent economies like Pakistan (Rahman et al., 2022).

FDI inflows positively contribute to emissions due to their association with energy-intensive industrial activities. The results support the pollution haven hypothesis,

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which posits that countries with lenient environmental regulations attract emission-intensive industries (Shahbaz et al., 2022). However, the negligible impact of negative FDI shocks indicates that emissions remain elevated even during periods of reduced investment. This highlights the need for stringent regulatory frameworks to ensure that incoming FDI aligns with environmental sustainability objectives (Zhang & Wang, 2022; Jiang et al., 2018).

ARDL and Non-Linear ARDL Analysis

The Autoregressive Distributed Lag (ARDL) model was employed to analyze both the long- and short-run dynamics of carbon emissions in response to economic growth, FDI, oil prices, renewable energy, and urbanization. The results confirm the presence of cointegration among the variables, indicating that these factors share a stable long-term relationship with carbon emissions. In the long run, renewable energy consumption was found to significantly reduce emissions, supporting previous studies by Apergis and Payne (2022). Urbanization exhibited a mixed impact, with poorly planned urbanization increasing emissions but well-implemented urban policies showing potential for reduction (Ali et al., 2023).

The Non-Linear ARDL (NARDL) model further revealed asymmetric effects of FDI and oil prices on emissions. Positive shocks in FDI inflows significantly increased emissions, consistent with the pollution haven hypothesis, while negative shocks showed negligible impact. Similarly, increases in oil prices were associated with reduced emissions due to energy conservation efforts, while price decreases led to heightened fossil fuel consumption (Rahman et al., 2022; Shin et al., 2014).

The dynamic multiplier effects from the NARDL analysis demonstrated that the short-term impacts of FDI and oil price fluctuations dissipate over time, transitioning into long-term equilibrium. This highlights the importance of targeted policies that address short-term shocks while fostering long-term sustainability.

Policy Implications

1. The results provide actionable insights for policymakers aiming to achieve a balance between economic growth and environmental sustainability: 1. Promote Renewable Energy Adoption: Measures should be made to ensure that adequate funds are put into the fixing of renewable energy systems. Subsidies and tax exemptions are examples of financial stimuli that can help increase the usage of specific renewable technologies like; solar, wind and hydropower (Ahmed et al 2023). Second, there is need to enhance public private partnerships so as to fund the missing link in the renewable energy sector (Wu et al., 2023).

2. Regulate FDI for Environmental Sustainability: It is, therefore, paramount to set definitive environmental measures that would check on FDI projects' emission rates. Promoting investment towards environmentally friendly tender, for example in renewable energy projects and environmentally friendly industrial processes, it is possible to move in harmony growth and environmental goals (Shahbaz et al., 2022;

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Tang & Tan, 2015).
3. Implement Sustainable Urban Planning: Urbanization policies should focus more on energy efficiency measures, and construction of green infrastructures. Infrastructural enhancement toward a smart city design that incorporates the incorporation of innovative public transport systems and renewable energy networks can lower urban emissions (Ali et al., 2023; Rahman et al., 2022).
4. Diversify Energy Sources: Increasing renewable power generation is the only solution to cut dependence on imported oil and gas and to address climate change. This is in contrast with global trends towards cleaner energy transitions (Apergis & Payne, 2022; Behera & Dash, 2017).

Results of Regression Analysis

These regression results have been captured in table above as regression output. The findings indicate the following:

• The coefficient for GDP per capita is positive and statistically significant at the 5% level ($p = 0.046$). This suggests that as economic development progresses, carbon emissions tend to increase, implying that growth activities are associated with higher environmental degradation, particularly in the early stages of development.

• FDI: The coefficient for foreign direct investment (FDI) is positive and statistically significant ($p = 0.003$), indicating that increased investment flows into the country are linked to rising carbon emissions. This supports the notion that FDI may promote carbon-intensive industries unless accompanied by strong environmental regulations.

• Oil Prices: The coefficient for oil prices is negative, though statistically insignificant at the 5% level ($p = 0.067$). Although it suggests that rising oil prices could theoretically help lower emissions through reduced consumption or efficiency improvements, the evidence is not strong enough to conclude a definitive relationship in this case.

• Renewable Energy: Renewable energy consumption exhibits a positive and statistically significant effect on carbon emissions ($p = 0.000$). This somewhat counterintuitive result may reflect the transitional stage of renewable energy development in the country, where the shift toward clean energy is still insufficient to offset the reliance on carbon-intensive sources.

• Urbanization: The coefficient for urbanization is positive but not statistically significant at the 5% level ($p = 0.055$). This suggests that while urbanization may contribute to carbon emissions, the effect is relatively weak and becomes important only when more efficient energy use policies are integrated into urban development plans

Interpretation of Regression Analysis

The regression analysis results add further understanding of other factors influencing carbon emissions. The results show that policy changes are needed to reverse the

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impacts of economic and investment activities on emissions because the coefficients for the **GDP per capita** and **FDI** are positive and statistically significant. Although the coefficient for the proportion of the **urban population** is positive, it is statistically insignificant, suggesting a moderate effect. It becomes quite evident that **renewable energy** also has a positive and statistically significant impact on emissions, reflecting that despite renewable energy initiatives, they are not yet sufficient to reduce carbon emissions at this stage. This study emphasizes the need for policymakers to promote the development of a low-carbon economy through the use of suitable policies (Ahmed et al., 2023; Wu et al., 2023)

Causality analysis

The Block Exogeneity Wald test, which displays the combined causality results of the long and short runs, is what we used for causality analysis. The causation results are shown in the table below. The causal relationship between economic growth and carbon emissions is bidirectional, indicating a feedback effect.

Dependent Variable	Independent Variable	Chi-Square Value	P-Value	Significance (5%)
CO2	GDP	0.012	0.9133	Not significant
FDI	Oil Prices	2.138	0.1451	Not significant
Oil Prices	Renewable Energy	0.133	0.7155	Not significant
Renewable Energy	Urbanization	14.28	0.0002	Significant
Urbanization	CO2	5.414	0.0209	Significant
CO2	Urbanization	2.483	0.1165	Not significant
Urbanization	CO2	13.081	0.0004	Significant

To understand the causal relationships between the variables, a Block Exogeneity

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Causality Test was conducted. This test assesses whether past values of one variable significantly contribute to predicting another variable in a Vector Autoregression (VAR) framework. The chi-square statistics, corresponding p-values, and significance levels are summarized in Table [X].

The results indicate significant causality relationships among the variables. For instance:

- **Urbanization → Renewable Energy Consumption**: The chi-square value of 14.28 ($p < 0.01$) confirms that urban expansion plays a vital role in driving renewable energy adoption. This aligns with previous findings (e.g., Sadowsky, 2014), emphasizing how urban growth stimulates cleaner energy alternatives due to increased demand and infrastructure development.
- **CO_2 emissions → Urbanization**: The causal effect from CO_2 emissions to urbanization is statistically significant ($\chi^2 = 5.41$, $p < 0.05$), suggesting that environmental degradation may influence population movements, planning, or urban policy adjustments—potentially leading to urban sprawl or shifts in urban growth patterns.
- **Foreign Direct Investment (FDI) → CO_2 emissions**: The chi-square value of 13.08 ($p < 0.01$) indicates a robust causal link, reinforcing the idea that increased FDI can lead to heightened industrial activity and, consequently, higher carbon emissions. This supports the pollution haven hypothesis in emerging economies. Apergis and Payne (2010).

These findings underline the interconnected dynamics between economic growth, energy consumption, and environmental degradation. Policies aimed at reducing emissions must consider these causal relationships to ensure sustainable development.

Results of Unit Root test

The unit root test results for all variables, including their test statistics and p-values, are presented in Table X. These findings ensured that the data met the prerequisites for advanced time series modeling, such as the ARDL and VAR methodologies used in this study.

Conclusion

This study aims at analyzing the interconnection between economic growth, FDI, oil price fluctuation, renewable energy consumption, and urbanization and their effects on CO2 emissions in the case of Pakistan. The Non-Linear ARDL and the standard ARDL analytical techniques further validate a co-directional and perspicuous grouping of these variables in the long run. Research work also points to the fact that even as people seek improvements in the economy and people's density thru growth and urbanization, these same processes act as vehicles of environmental degradation and pollution. On the other hand, renewable energy is identified as the best way to reduce carbon emission and take a better future path for the country's development.

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Another significant factor analyzed in the work is the inclination or decoupling impact of FDI and oil prices on carbon emissions. While an improvement in the FDI stock enhances economic growth, there is a negative association between FDI and carbon emissions. This shows that Pakistan has to tighten its environmental policies and attract more green investments or funds. Likewise with regard to emissions, increases in oil price have varied impacts while reductions have varied impacts. This finding shows that the country needs to start looking for energy diversification to alleviate the susceptibility of the environmental imprint to global market forces.

From policy considerations, the study implies that there is required policy coordination between economic development and environmental conservation. The study calls for investments in renewable energy as a way of minimizing carbon emission and establishing a long-term energy security. Further, advancement of urban design a sustainable dimension is critically vital in minimizing the impacts of rapidly growing cities. Improvement on these areas requires that supportive regulatory policies be firmly established to prevent industries that are environmentally sensitive from degrading the ecological systems regulators of the economic growth.

Other findings also play an important concern of how green technologies and sustainable practices can also mitigate environmental impacts. Through implementation of these solutions, the country stands to reduce the extent of harm that could be bestowed on the environment by the existing development course. The outcomes of the study are parallel to what Pakistan pledged on signing the Paris Agreement whereby the country has been encouraged to take measures towards limiting the effects of global warming the emission of carbon. This has a clear roadmap that can be used by the policy makers to integrate sustainability and make future development suitable for economic gains as well as the sustainability of the environment.

Finally, the building of a low-carbon economy has become not only a policy direction but also a developmental imperative. Consequently, this contemporary research can be considered as the first step of the agenda that can help Pakistan to find roads towards sustainability. As such, the study enlightens policymakers and other stakeholders with the required knowledge and evidence to deal with the inter-connectedness of economic growth and environmental sustainability for the development of a sustainable future for Pakistan.

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