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The Causal Connection between CO_2 Emissions and Agricultural Productivity in Pakistan: Empirical Evidence from an Autoregressive Distributed Lag Bounds Testing Approach

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Abstract: The rapid agricultural development and mechanization of agronomic diligence has led to a significant growth in energy consumption and CO_2 emission. Agriculture has a dominant contribution to boosting the economy of any country. In this paper, we demonstrate carbon dioxide emissions' association with cropped area, energy use, fertilizer offtake, gross domestic product per capita, improved seed distribution, total food grains and water availability in Pakistan for the period of 1987-2017. We employed Augmented Dickey-Fuller and Phillips-Perron unit root tests to examine the variables' stationarity. An autoregressive distributed lag (ARDL) bounds testing technique to cointegration was applied to demonstrate the causality linkage among study variables from the evidence of long-run and short-run analyses. The long-run evidence reveals that cropped area, energy usage, fertilizer offtake, gross domestic product per capita and water availability have a positive and significant association with carbon dioxide emissions, while the analysis results of improved seed distribution and total food grains have a negative association with carbon dioxide emissions in Pakistan. Overall, the long-run effects are stronger than the short-run dynamics, in terms of the impact of explanatory variables on carbon dioxide emission, thus making the findings heterogeneous. Possible initiatives should be taken by the government of Pakistan to improve the agriculture sector and also introduce new policies to reduce the emissions of carbon dioxide.

Keywords: Pakistan; agriculture production; CO_2 emission; climate change; energy use; food grains

1. Introduction

The population of the world is growing rapidly, and demand for food is increasing with the passage of time, which leads to an increase in the productivity of agriculture. Competitiveness between large, regional producers and individual farms has stimulated a concentration on agricultural growth. As a consequence, the production of livestock is concentrated in specific areas, while other areas are concerned with crop production and lack of fertilizers. This intensification regarding farms has been observed worldwide, and has also been discussed in regard to its ecological effect and the potential reintegration of crops and livestock systems [1,2]. The continuing menace posed by climate change causes carbon dioxide (CO_2) emission, which has rekindled steadfast global encouragement against its harmful derivatives. A key challenge to agriculture and food security in the world is climate change because of its impact on production and enforcement sector, which limits global warming [3].

Furthermore, with the prospect of bringing on the failure of the largest market in the world, climate change is considered a serious environmental threat in the 21st century. The adverse effects of climate change impose additional costs on developing countries in attaining their developmental goals. They also affect the agricultural production and steady economic growth, and cause water and food shortages, an increased loss of forestry, and huge immigration issues [4]. The latest estimates reveal that global CO_2 emissions are unstable and have grown significantly in the last century. Evidently, it is among those factors behind the progress in economic growth. Consideration of greenhouse gas emissions is crucial for economic planning, decision making and environmental development. CO_2 is currently considered the chief contributor to anthropogenic greenhouse gas emissions. According to the Intergovernmental Panel on Climate Change (IPCC), CO_2 accounts for about 76.7% of greenhouse gas emissions; 56.6% is from the fossil fuels, about 17.3% is from deforestation, and 2.8% is from the other sources [5].

In emerging economies, CO_2 emission holds a huge share among pollutants in total greenhouse gas emissions. Due to a rapidly growing population, the demand for energy, economic growth, and agricultural production is rising and CO_2 emissions are increasing with the passage of time [6–9]. With a rapidly growing population, global agricultural production has increased from the mid-20th century. The global demand for food has doubled, creating a threat to a sustainable environment and agriculture.

The agricultural sector is considered the major source of greenhouse gas emissions because agricultural practices are not sustainable enough to improve productivity and enhance food security [10–12]. It is extensively assumed that agriculture plays a dominant role in achieving the objective of CO_2 emission reduction. Similarly, the agricultural sector is hugely dependent on climate, temperature, rainfall and floods. It affects agricultural production, the food supply, commodity prices and other aspects that eventually decrease economic performance [13,14]. Globally, agriculture produces 20% of CO_2, methane produces 70% and nitrogen oxide produces about 90% [15].

The agricultural sector plays a key role in the upsurge of economic growth of any country by enhancing economic development. Several studies have highlighted CO_2 emissions and their association with energy consumption, economic growth, agricultural growth, natural gas consumption, renewable and sustainable energy, economic and population growth, forest and agriculture and renewable waste [16–26]. In this study, we demonstrate the association between CO_2 emissions and agricultural production in Pakistan, including cropped area, energy use, fertilizer offtake, gross domestic product (GDP) per capita, improved seed distribution, total food grains and water availability. As agriculture is considered the backbone of Pakistan's economy, it has a rich contribution to boosting the economy.

The paper is organized as follows: the Related Literature section deals with our review of existing literature. The Methodology section presents the method of the study. The Results and Discussion section show the results of the summary statistics and correlation matrix, unit root tests, autoregressive distributed lag (ARDL) model to cointegration, the Johansen cointegration tests and the analysis of the long-run and short-run evidence. The Conclusion and Recommendations section relate conclusions from the study and the resulting policy recommendations.

2. Related Literature

The contribution of the agriculture sector is 14-30% of worldwide greenhouse gas emissions, due to rigorous use of fossil fuel energy. Agricultural use of fuel-driven agricultural equipment, irrigation, production of livestock and use of nitrogen-rich fertilizers produce huge greenhouse gas emissions. The Food and Agriculture Organization (FAO) believes that the agricultural sector has enormous potential to decrease its emissions, including eradicating 80–88% of recent CO_2 emissions [27]. Regarding CO_2 emission, in certain cases, the activities of humans are chiefly responsible. In power generation, economic activity involves the combustion of fuel, as does activity in the residential, industrial and transportation sectors, which causes an upsurge in greenhouse gases. In recent times, the environmental consequences of economic growth have been progressively reviewed. Consequently, in the previous few decades, economic growth trends and activities have steadily changed from pretentious growth to eco-friendly growth [28]. CO_2 emission has been influenced on several levels, including population growth, economic growth, resource endowments, technological changes, lifestyle and transport patterns [29]. In fact, the intensification in CO_2 emission is a major threat of climate change, which is a key concern for the developing, as well as for the developed nations. In the developed countries, economic growth stimulates the rigorous usage of energy, which leads to environmental degradation. In recent years, CO_2 emissions are considered the key source of the greenhouse effect and have garnered intense attention [30].

The interrelationship between CO_2 emission and economic growth raises the energy demand. Environmental degradation, consumption of energy and economic growth are considered in the framework of the Environmental Kuznets Curve, which assumes that in low-income countries, pollutant emissions have increased; but in high-income countries, emissions have decreased [31]. The huge escalation in greenhouse gas emissions is primarily accredited to CO_2 being the chief foundation of climate change and global warming. The prescribed economy has turned into a major donor to CO_2 emissions. Correspondingly, the informal economy has also begun to influence the quality of the environment. By permitting polluting Small to Medium Enterprises (SMEs) to dodge environmental regulations, growth in the casual economy may raise the level of pollution and contribute to the degradation of the environment [32–34]. A large amount of CO_2 emissions can be removed from the soil and crop management through soil organic substance. Examples include reducing tillage and non-tillage, changing land use from cultivated land to permanent crops and restoration of degraded land [35].

It has been observed that CO_2 emission and climate change is associated with agricultural productivity. The agriculture sector is an imperative source of CO_2 emissions and is also considered with utmost susceptible climate change. Globally, the agriculture sector has slightly lower CO_2 emissions than the thermodynamics industry. It is essential to decrease agricultural-related emission of CO_2 and extend low-carbon agriculture, which have been taken seriously for the economic development and rising controlled environment and energy [36–38]. Approximately 25% of the world's population belongs to South Asian countries. Agriculture is a lifeline in these developing economies, so these countries must be self-sufficient in producing food supplies [39].

Agricultural production, natural resources, infrastructure, human living environments and economic and energy losses are associated with environmental degradation, which is an important factor in world development. Energy plays a critical role in the human, social and economic progress required for sustainable development. Estimates for 2010-2040 show that energy consumption will increase by 56%. This upsurge in energy consumption causes CO_2 emissions, which is the chief component of total greenhouse gas emissions. Approximately 61.4% of greenhouse gases come from the energy sector [40–42]. If the temperature increases globally, renewable energy will reduce CO_2 emissions by approximately 50% by 2050. The use of renewable energy is also advantageous to farmers, in the social, economic and environmental sense. The marvelous growth in the agricultural sector and future growth in the Pakistani economy highlight the growing demand for energy [43–45].

Figures 1–8 indicate the trends in CO_2 emissions, cropped area, energy use, fertilizer offtake, GDP per capita, improved seed distribution, total food grains and water availability in Pakistan.

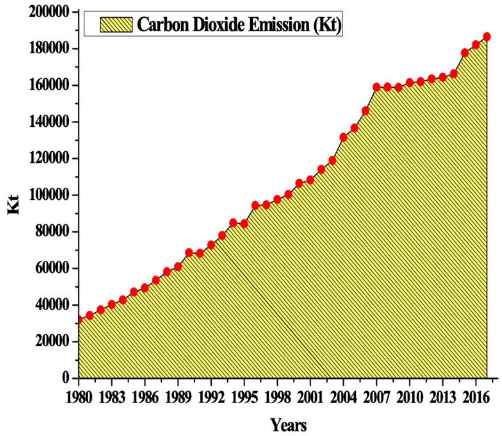

Figure 1. CO_2 Emission (Kt).

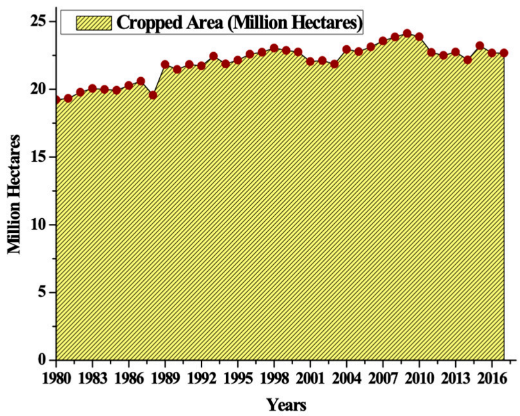

Figure 2. Cropped Area (Million Hectares).

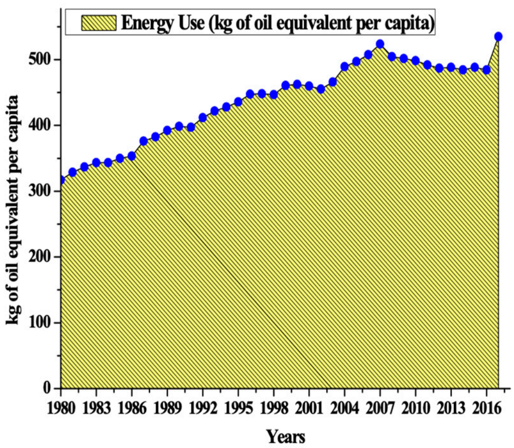

Figure 3. Energy Use (kg of oil equivalent per capita).

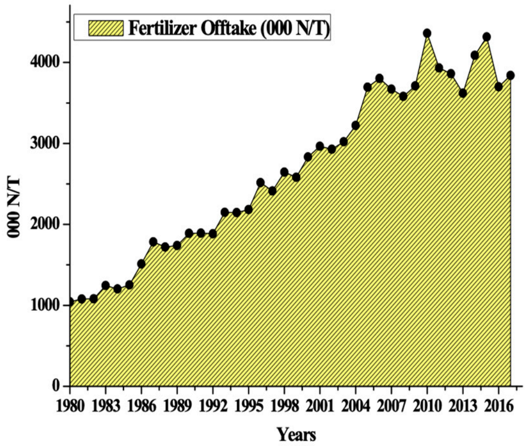

Figure 4. Fertilizer Offtake (000 N/T).

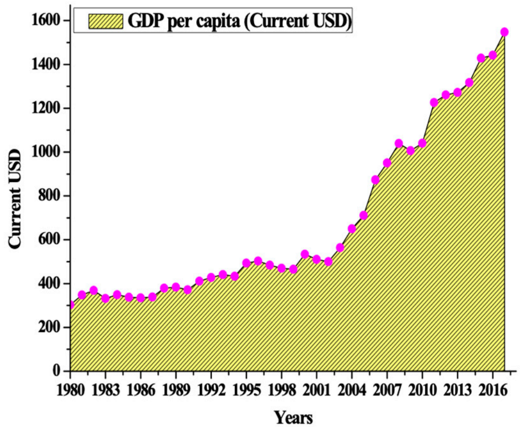

Figure 5. GDP per capita (Current USD).

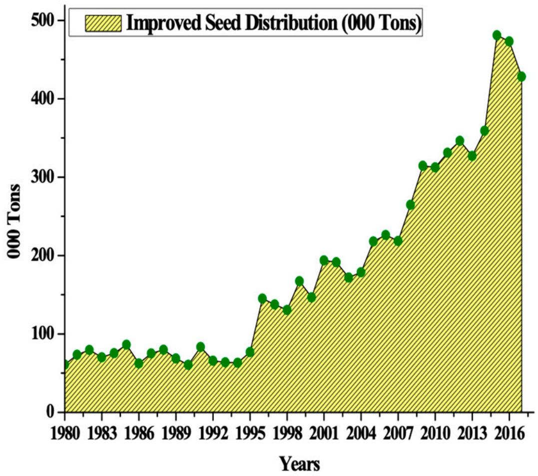

Figure 6. Improved Seed Distribution (000 Tons).

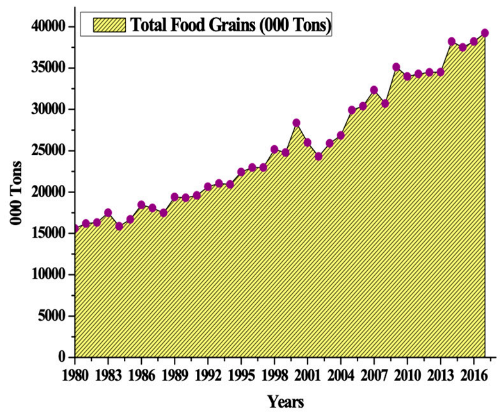

Figure 7. Total Food Grains (000 Tons).

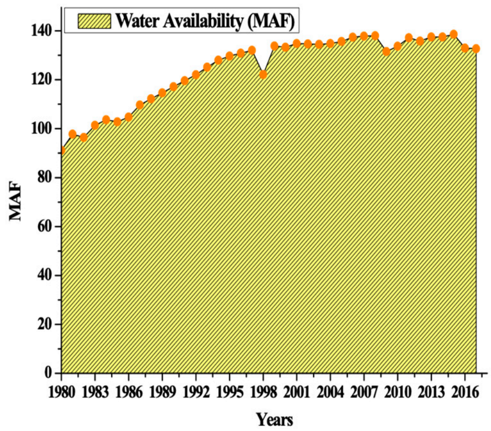

Figure 8. Water Availability (MAF).

3. Materials and Methods

3.1. Sources of Data

We used time-span data from 1987-2017 collected from the World Development Indicators 2017 database and the Government of Pakistan's Economic Survey of Pakistan 2016-17. The variables used in the study are explained in Table 1, below.

Table 1. Variables description and data sources.

Variables	Explanation	Data Sources
CO_2e	Carbon dioxide emission (kt)	WDI
CA	Cropped Area (Million Hectares)	GOP
EN	Energy Use (kg of oil equivalent per capita)	GOP
FO	Fertilizer Offtake (N/T)	GOP
GDPPC	GDP per capita (current USD)	WDI
ISD	Improved Seed Distribution (tons)	GOP
TF	Total Food Grains (tons)	GOP
WA	Water Availability (MAF)	GOP

Note: GOP stands for Government of Pakistan.

Table 1 describes the variables, including CO_2 emission in Kt, cropped area per million hectares, energy use in kg of oil equivalent per capita, fertilizer offtake in N/T, GDP per capita in current USD, improved seed distribution in tons, total food grains in tons and water availability in MAF.

3.2. Econometric Model Specification

We will specify the following model to check the association between dependent and independent variables:

$$CO2e_t = f(CA_t, EN_t, FO_t, GDPPC_t, ISD_t, TF_t, WA_t) \tag{1}$$

In the above Equation (1), $CO2e_t$ = carbon dioxide emission in (kt); CA_t = cropped area in million hectares; EN_t = energy use in kg of oil equivalent per capita; FO_t = fertilizer offtake in N/T; $GDPPC_t$ = gross domestic product per capita in current USD; ISD_t = improved seed distribution in tons; TF_t = total food grains in tons and WA_t = water availability in MAF. We can also write Equation (1) as;

$$\begin{gathered} CO2e_t = \delta_0 + \delta_1 CA_t + \delta_2 EN_t + \delta_3 FO_t + \delta_4 GDPPC_t + \delta_5 ISD_t \\ +\delta_6 TF_t + \delta_7 WA_t + \mu t \end{gathered} \tag{2}$$

By employing the logarithm to Equation (2), the model follows a log-linear form:

$$\begin{gathered} lnCO2e_t = \delta_0 + \delta_1 lnCA_t + \delta_2 lnEN_t + \delta_3 lnFO_t + \delta_4 lnGDPPC_t \\ +\delta_5 lnISD_t + \delta_6 lnTF_t + \delta_7 lnWA_t + \mu t \end{gathered} \tag{3}$$

Equation (3) is the log-linear form of the variables. $lnCO2e_t$ displays the natural logarithm of CO_2 emission. $lnCA_t$ displays the natural logarithm of the cropped area. $lnEN_t$ displays the natural logarithm of energy use. $lnFO_t$ shows the natural logarithm of fertilizer offtake. $lnGDPPC_t$ shows the natural logarithm of GDP per capita. $lnISD_t$ displays the natural logarithm of improved seed distribution. $lnTF_t$ shows the natural logarithm of total food grains. $lnWA_t$ displays the natural logarithm of water availability. t demonstrates the dimension of time. μt indicates the error term. The model coefficients δ_1 to δ_7 demonstrate long-run elasticity.

The stationarity of the variables was checked by employing the Augmented Dickey-Fuller [46] and Phillips-Perron [47] unit root tests. The null hypothesis is the drift of the unit root, and the two substitute hypotheses are that the series does not have a unit root with a linear time trend, and that the series has a non-zero mean and a stable trend, with no time trend. Equation (4), below, presents the unit root test.

$$\Delta U_t = \alpha_\circ + \partial_\circ T + \partial_1 U_{t-1} + \sum_{i=1}^{m} \alpha_1 \Delta U_{t-1} + \mu_t \tag{4}$$

In Equation (4), the variable U demonstrates the unit root test. Δ show the first difference. T is the linear trend. t indicates the time. m represents the white noise residuals to achieve.

3.3. Specification of ARDL Model

The ARDL model was estimated by Pesaran and Shin (1998) [48] to check the analysis of long-run and short-run relationships. It was further protracted by Pesaran et al. (2001) [49]. Narayan et al. (2004) [50] also used this model in a study to check the variables' associations. The order of integration is distributed with variables at I(0) or I(1) apart from the occurrence of I(2). Here we will demonstrate separately the long-run and short-run models, to check the variables' associations. The long-run model is depicted in Equation (5), below:

$$\begin{aligned}\Delta lnCO2e_t &= \phi_0 + \sum_{i=1}^{Q} \phi_{1i}\Delta lnCO2e_{t-i} + \sum_{i=1}^{W} \phi_{2i}\Delta lnCA_{t-i} \\ &+ \sum_{i=1}^{E} \phi_{3i}\Delta lnEN_{t-i} + \sum_{i=1}^{R} \phi_{4i}\Delta lnFO_{t-i} \\ &+ \sum_{i=1}^{T} \phi_{5i}\Delta lnGDPPC_{t-i} + \sum_{i=1}^{Y} \phi_{6i}\Delta lnISD_{t-i} \\ &+ \sum_{i=1}^{U} \phi_{7i}\Delta lnTF_{t-i} + \sum_{i=1}^{I} \phi_{8i}\Delta lnWA_{t-i} \\ &+\delta_1 lnCO2e_{t-1} + \delta_2 lnCA_{t-1} + \delta_3 lnEN_{t-1} \\ &+\delta_4 lnFO_{t-1} + \delta_5 lnGDPPC_{t-1} + \delta_6 lnISD_{t-1} \\ &+\delta_7 lnTF_{t-1} + \delta_8 lnWA_{t-1} + \varepsilon_t\end{aligned} \tag{5}$$

In Equation (5), ϕ_0 indicates the constant intercept. Δ is the difference operator. Q, W, E, R, T, Y, U and I illustrate the order of lags. δ is the coefficient of the long-run, and ε_t is the error term. Pesaran et al. (2001) demonstrated that the two values may be used for the cointegration: first for the lower bound, where the variables are integrated at zero-order, followed by the upper limit bound value, where variables are integrated at order one. The short-run model estimation of the study variables is illustrated by following the error correction model (ECM) in ARDL and is specified as:

$$\begin{aligned}\Delta lnCO2e_t &= \phi_0 + \sum_{i=1}^{A} \phi_{1i}\Delta lnCO2e_{t-i} + \sum_{i=1}^{S} \phi_{2i}\Delta lnCA_{t-i} \\ &+ \sum_{i=1}^{D} \phi_{3i}\Delta lnEN_{t-i} + \sum_{i=1}^{F} \phi_{4i}\Delta lnFO_{t-i} \\ &+ \sum_{i=1}^{G} \phi_{5i}\Delta lnGDPPC_{t-i} + \sum_{i=1}^{H} \phi_{6i}\Delta lnISD_{t-i} \\ &+ \sum_{i=1}^{J} \phi_{7i}\Delta lnTF_{t-i} + \sum_{i=1}^{K} \phi_{8i}\Delta lnWA_{t-i} + \alpha ECM_{t-1} \\ &+\varepsilon_t\end{aligned} \tag{6}$$

Equation (6) show the analysis of the short-run among study variables by the ECM. A, S, D, F, G, H, J and K represent the order of lags in the equation.

4. Results and Discussion

4.1. Summary Statistics and Correlation Matrix

The results of the summary statistics and correlation matrix are interpreted in Table 2. The results show that all variables are normally distributed, which is indicated by the Jarque-Bera statistics and probability values. The correlation analysis indicates that there is an existing positive correlation between CO_2 emission and cropped area, energy usage, fertilizer offtake, GDP per capita, improved seed distribution and total food grains.

Table 2. Summary statistics and correlation matrix results.

Variables	$LNCO_{2e}$	LNCA	LNEN	LNFO	LNGDPPC	LNISD	LNTF	LNWA
Mean	11.62931	3.272286	6.127777	7.960351	6.509023	5.129763	10.19537	4.866836
Median	11.64469	3.124125	6.136581	7.994980	6.280138	5.186100	10.16531	4.892452
Maximum	12.13631	4.144583	6.282379	8.380340	7.344624	6.175867	10.57740	4.931520
Minimum	10.88808	3.025291	5.929937	7.450080	5.826250	4.105120	9.768298	4.697932
Std.Dev.	0.379787	0.366298	0.095564	0.303646	0.492566	0.667094	0.248322	0.065605
Skewness	−0.367964	1.827603	−0.538492	−0.328698	0.367273	−0.144394	−0.046627	−1.230197
Kurtosis	1.875204	4.427214	2.289894	1.704256	1.596638	1.764649	1.735385	3.361083
Jarque-Bera	2.333727	19.88839	2.149521	2.726867	3.240772	2.078926	2.076932	7.987565
Probability	0.311342	0.000048	0.341380	0.255781	0.197822	0.353645	0.353997	0.018430
Observations	31	31	31	31	31	31	31	31
$LNCO_{2e}$	1.000000							
LNCA	0.287692	1.000000						
LNEN	0.960217	0.195537	1.000000					
LNFO	0.980246	0.233428	0.945762	1.000000				
LNGDPPC	0.940177	0.365944	0.845598	0.908828	1.000000			
LNISD	0.946856	0.380386	0.869403	0.945105	0.927329	1.000000		
LNTF	0.976124	0.304974	0.915322	0.961370	0.962135	0.953546	1.000000	
LNWA	0.875045	0.080978	0.899151	0.862026	0.715330	0.768892	0.799829	1.000000

4.2. Unit Root Test Results

Tables 3 and 4 report the results of the Augmented Dickey-Fuller and Phillips-Perron unit root tests.

Table 3. Augmented Dickey-Fuller Unit root test results.

Variable	ADF Test Statistics (at Levels)	ADF Test Statistics (at First Difference)	(Status)
$LNCO_{2e}$	0.947208	−4.057989 **	I(1)
LNCA	−3.465301 *	-	I(0)
LNEN	−1.999591	−3.345375 *	I(1)
LNFO	0.626924	−5.871416 ***	I(1)
LNGDPPC	−1.592687	−5.045839 ***	I(1)
LNISD	−3.446940 *	-	I(0)
LNTF	−4.780429 ***	-	I(0)
LNWA	−2.294522	−8.244225 ***	I(1)

Table 4. Phillips-Perron Unit root test results.

Variable	P-P Test Statistics (at Levels)	P-P Test Statistics (at First Difference)	(Status)
$LNCO_{2e}$	−1.486801	−6.911246 ***	I(1)
LNCA	−3.465301 *	-	I(0)
LNEN	−2.034168	−3.345375 *	I(1)
LNFO	−1.849628	−9.749996 ***	I(1)
LNGDPPC	−1.646333	−5.041999 ***	I(1)
LNISD	−3.429725 *	-	I(0)
LNTF	−4.738381 ***	-	I(0)
LNWA	−1.955929	−19.51462 ***	I(1)

***, ** and *indicates the level of significance at 1%, 5% and 10%.

None of the variables got integration in the order of I(2) by indicating the results of the Augmented Dickey-Fuller and Phillips-Perron unit root tests; therefore an ARDL model was employed.

4.3. Cointegration Test

The cointegration test is performed when the value of the F and W statistics use the upper bound of the designated level of significance. It is assumed that the F statistics have no cointegration null hypothesis among the study variables. The cointegration results at 1%, 5% and 10% significance level are illustrated in Table 5, while the results of the Johansen cointegration [51], with trace statistics and maximum eigenvalue statistics with critical values, are interpreted in Table 6.

Table 5. Autoregressive Distributed Lag (ARDL) bounds test for cointegration results.

F-Statistic	Significance Levels	Lower Bound	Upper Bound	Status
3.870465	10 percent	2.03	3.13	Co-integrated
	5 percent	2.32	3.50	
	1 percent	2.96	4.26	

In Table 5, the ARDL model to bounds testing results reveal and recapitulate the occurrence of a cointegration linkage among the study variables at 1%, 5% and 10% significance levels.

Table 6. Johansen cointegration test results.

Null Hypothesis	Trace Test Statistic	P-value	Null Hypothesis	Maximum Eigenvalue	*P*-value
$r \leq 0$	232.7068 *	0.0000	$r \leq 0$	77.65021 *	0.0000
$r \leq 1$	155.0566 *	0.0002	$r \leq 1$	48.54521	0.0278
$r \leq 2$	106.5114 *	0.0074	$r \leq 2$	31.58198	0.3264
$r \leq 3$	74.92944 *	0.0184	$r \leq 3$	33.87687	0.1492
$r \leq 4$	45.33503	0.0846	$r \leq 4$	27.58434	0.0798
$r \leq 5$	19.38669	0.4654	$r \leq 5$	21.13162	0.5728
$r \leq 6$	7.639644	0.5047	$r \leq 6$	14.26460	0.8568

Note: r show the cointegrating equation numbers; * denotes hypothesis rejection at the 0.05 level.

Table 6 indicates the results of the Johansen cointegration test with trace statistics and max-eigenvalue.

4.4. Long-Run and Short-Run Evidence

The results of the long-run and short-run evidence interpreted with the residual diagnostic test are presented in Table 7, below.

Table 7. Long-run and short-run evidence results.

Variable	Coefficient	Std. Error	T- Ratio	*P*-value
Dependent variable is lnCO_{2e}: ARDL(1, 1, 0, 1, 1, 0, 0, 1) selected based on AIC				
Panel A: long-run Analysis				
LNCA	0.072391	0.026865	2.694625	0.0148
LNEN	0.826146	0.241722	3.417754	0.0031
LNFO	0.607328	0.136929	4.435357	0.0003
LNGDPPC	0.211959	0.054088	3.918779	0.0010
LNISD	−0.042691	0.041699	−1.023784	0.3195
LNTF	−0.031709	0.158234	−0.200393	0.8434
LNWA	0.706882	0.245003	2.885204	0.0099
C	−2.742992	1.074045	−2.553890	0.0199
Panel B: Short-run Analysis				
Δ LNCA	0.031187	0.015035	2.074271	0.0527
Δ LNEN	0.615764	0.203512	3.025696	0.0073
Δ LNFO	0.312632	0.088522	3.531681	0.0024
Δ LNGDPPC	−0.046796	0.078172	−0.598633	0.5569
Δ LNISD	−0.031819	0.030053	−1.058762	0.3037
Δ LNTF	−0.023634	0.116811	−0.202329	0.8419
Δ LNWA	0.206519	0.209902	0.983881	0.3382
ECM (−1)	−0.745345	0.136764	−5.449872	0.0000
Panel C. Residual Diagnostic Test				
		R-squared	0.997706	
		Adjusted R-squared	0.996086	
		Durbin-Watson stat	2.698081	
		F-statistic	16.0557***	
χ2 SERIAL	1.7655 (0.202)			
χ2 NORMAL	0.0724 (0.964)			
χ2ARCH	0.1557 (0.696)			
χ2 RESET	0.7142 (0.48)			

Note: ** and *** signify the probability and the significance level at 5% and 10%. χ^2 SERIAL show the serial correlation, χ^2 NORMAL indicates the normality test, χ^2ARCH indicates the autoregressive conditional heteroskedasticity test and χ^2 RESET represents Ramsey Reset test with their p-values.

Table 7 represents the results of the long-run and short-run evidence in Panel A and Panel B. Focusing on the long-run evidence with elasticity in the Panel A variables, the results indicate that cropped area, energy use, fertilizer offtake, GDP per capita and water availability have a significant association with CO_2 emission, having p-values of 0.0148, 0.0031, 0.0003, 0.0010 and 0.0099, respectively. The long-run analysis results conclude that a 1% increase in all variables—including cropped area, energy use, fertilizer offtake, GDP per capita and water availability has a positive correlation, with CO_2 emission increases of 0.07%, 0.82%, 0.60%, 0.21% and 0.70%, respectively. In the long-run evidence, the analysis results regarding CO_2 emission and cropped area, energy use, fertilizer offtake, GDP per capita and water availability have a positive and significant association. The analysis results also show that improved seed distribution and total food grains have a negative linkage to CO_2 emission in Pakistan. In South Asia, Pakistan has a dominant role and is greatly affected by a number of influences, including temperature variations, pests, health problems, droughts and other changes the country is likely to endure in the future. The linkage between CO_2 emission and energy consumption enhances the maximum energy consumption of about 640 kg per capita of oil equivalent. Recently, the economic maneuver is lower than its level, but it is expected that CO_2 emissions will endure and rise progressively over a period of time until the level of threshold is extended [52].

The change in the climate in Pakistan is fundamentally caused by the emission of greenhouse gasses. The key source of greenhouse gas emissions is the activities of humans, such as deforestation, urbanization, industrialization, transportation, agriculture, waste, energy use and livestock [53]. Some studies emphasize the linkage of CO_2 emission with agriculture policies, agriculture land expansion and deforestation, greenhouse gas emission mitigation in agriculture, climatic variations and congestion influence on productivity [54–58]. However, our study demonstrated the linkage of CO_2 emissions to agricultural productivity, including cropped area, energy use, fertilizer offtake, gross domestic product per capita, improved seed distribution, total food grains and water availability in Pakistan. Long-run evidence results showed a positive influence regarding cropped area, energy use, fertilizer offtake, GDP per capita and water availability, but improved seed distribution and total food grains had a negative linkage with CO_2 emissions in Pakistan. Regarding improved seed distribution and total food grains that have a negative linkage with CO_2 emission, possible policy implications should be taken by the government of Pakistan to cut CO_2 emission from these sources. Conceivable funding schemes will also be needed to boost agricultural productivity in the country, to increase economic growth and development.

Panel B depicts the short-run analysis results and their association to the study variables; an ECM requires the cointegration presence to incarceration the short-run dynamics and relation with its coefficients that measures the adjustment speed. In the short-run evidence, the results indicate that cropped area, energy use, fertilizer offtake and water availability coefficients have a significant linkage with CO_2 emissions in Pakistan, with p-values of 0.0527, 0.0073, 0.0024 and 0.3382, respectively, which means a 1% increase in all variables has a positive association with CO_2 emission increases of 0.03%, 0.61%, 0.31% and 0.20%, respectively. Similarly, in the short-run evidence, the variables GDP per capita, improved seed distribution and total food grains have a negative linkage with CO_2 in Pakistan. There are several issues in Pakistan, including the lack of social and health services, insufficient agricultural productivity, economic instability and development and a rapidly growing population that affect the living standards of the Pakistani people [59]. The local climate in the country is usually hot in the summer and cold in the winter, with low rainfall, because the country is located in a temperate zone [60]. Agriculture, renewable energy consumption and forestry have a dominant role in mitigating CO_2 emission. However, agricultural productivity has a contrary influence on the environment. The forest also has a huge impact in reducing CO_2 emission.

The analysis results in Panel C show that the R-squared value is 0.997706, which indicates 99% variation in the CO_2 emission described in the model. The adjusted R-squared value is 0.996086. The F statistic shows the joint significance as 1%, confirmed regarding the independent variables. The Durbin-Watson statistic value is 2.698, which shows the non-appearance of any autocorrelation and is not equal to the Durbin-Watson standard value, but is enough to expose any autocorrelation in the model.

4.5. Structural Stability Test

The CUSUM test and CUSUM Square test graphs are stated in Figures 9 and 10, which specify the level of significance at 5%; this demonstrates the stability test to stable the long-run and short-run constraints.

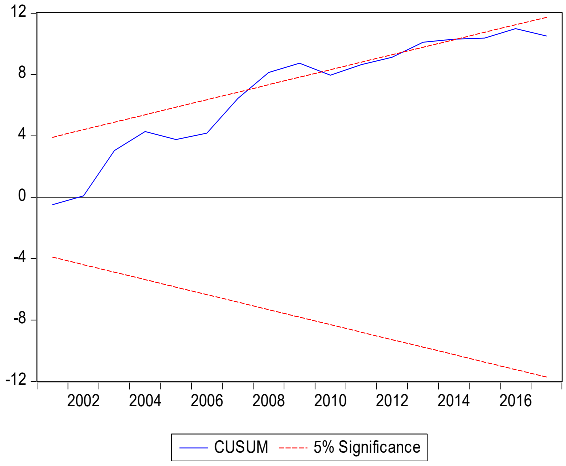

Figure 9. Plot of CUSUM.

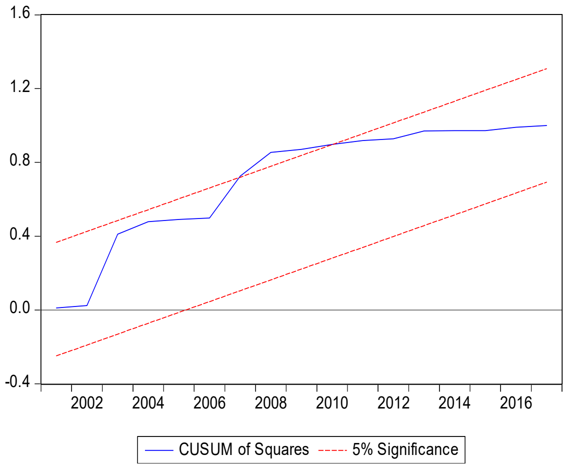

Figure 10. Plot of CUSUM of Square.

5. Conclusion and Recommendations

The key motive of this study was to check the linkage of CO_2 emissions with agricultural productivity in Pakistan, including cropped area, energy use, fertilizer offtake, GDP per capita, improved seed distribution, total food grains and water availability. We employed Augmented Dickey-Fuller and Phillips-Perron unit root tests to check the variables' stationarity. An ARDL bounds testing approach to cointegration was applied, with the evidence of long-run and short-run analysis, to enhance the causality association among the variables.

The analysis of the long-run evidence exposed that CO_2 emission has a positive and significant association with cropped area, energy use, fertilizer offtake, GDP per capita and water availability in Pakistan, while the analysis results show that improved seed distribution and total food grains have a negative linkage with CO_2 emissions in Pakistan. Similarly, the analysis results from the short-run evidence exposed that cropped area, energy use, fertilizer offtake and water availability coefficients have a positive and significant linkage with CO_2 emissions in Pakistan, while the variables GDP per capita, improved seed distribution and total food grains have a negative linkage with CO_2 emission in Pakistan.

In the light of this study, possible solutions should be implemented by the government of Pakistan to further reduce CO_2 emissions and to enhance agricultural productivity. As the country is also facing other severe crises, including energy production and supply from different sources. It is necessary that there should also be attention prerequisite in the agricultural sector to boost agriculture sector by providing the necessary facilities and funding schemes to enhance rapid economic growth and development.

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