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Exploring the Impact of Energy Consumption, Food Security on CO_2 Emissions: a Piece of New Evidence from Pakistan

Snovia Naseem*, Tong Guangji*,[1], and Umair Kashif*

Abstract *– Adopting a co-integration approach of asymmetric Autoregressive Distributed Lag (ARDL), this article seeks to examine the asymmetrical effect of agriculture, energy consumption, and food security on carbon emission of Pakistan from 1970 to 2019. Multiple unit root tests (ADF, PP, and KPSS, Z and A) were used to verify the data stationarity and structural breaks and also used population data as a food security proxy indicator. Our foremost objective of this analysis is to investigate that agricultural results related to CO_2 emissions are asymmetrical or not for Pakistan. Our outcome endorses the existence of the asymmetrical effect of agriculture on CO_2 in the short- and long-term. Furthermore, the results of population and energy consumption increase environmental degradation. Based on the study findings, the government would need to adopt concrete measures towards effective policymaking and addressing environmental issues in Pakistan.*

Keywords *– agriculture, CO_2 mitigation, food security, NARDL, structural break.*

1. INTRODUCTION

Globally, environmental degradation issues are increasing due to anthropological activities such as population growth, industrialization, and other various agricultural practices [2]. However, efforts have been made to save or mitigate the worst effects of climate change at the global level. For this purpose, numerous seminars and conferences are held annually across the world to highlight this topic [3]. An agreement was signed in France (called the Paris Agreement, 2016), wherein 196 signatories' countries agreed to strengthen their attempts to address the climate change issues with sufficient resources and advanced technologies. Following the agreement, participating signatories develop their national action plan to enhance environmental policy [4].

Pakistan is one of the signatories of 196 countries, which is also contributing to CO_2 by generating 192.7 million tons of emissions annually [5]. Pakistan is the second-most in the South Asian region and ranks eighth in the CO_2-affected countries worldwide [6]. The leading cause of this significant climate disruption is the use of oil- and gas-based energy, which accounts for 80 percent of the country's total energy output. In addition, energy demand has recently risen significantly due to transportation, industrial, and urbanization [7]. Besides the above mention sources, there are other factors as well that held responsible for the ecological problems, such as agriculture and food security.

Agriculture plays a significant role in the growth of Pakistan, and also serves as a cornerstone of the economy. In the meantime, approximately 41 percent of the effects of climate change emerged from forestry, livestock, and different other land uses [8]. The forecast for agricultural nitrous oxide will be 35 to 60% by 2030. These escalations are due to the increase in nitrogen fertilizer and the production of animal manure. Such composts also influence the total agricultural output and reduce the share of farming, which was recorded as 38.9% in the 1970s and 19.3% in 2019 [9]. The reported falloff in the percentage of agriculture because of CO_2 is an alarming indication for a country regarded as an agrarian. These indicators will pose a threat of food security to a nation that has the fastest population growth rate in the entire region. Figure 1 represents the South Asia map of Köppen's climate classifications.

Moreover, as per the population census of Pakistan (2017), there are more than 212 million people lives in Pakistan; 58 percent of whom faced the issue of malnutrition, while 18 percent faced food shortage due to changes in atmospheric temperatures, and this ratio is growing progressively. Likewise, the Global Hunger Index allocates 32.6 percent points from 0-100 to Pakistan, where 0 indicates hunger-free. Pakistan placed at 106 out of 119 underdeveloped countries, which were categorized as a "severe" food insecure nations group. However, Pakistan is continuously working to tackle the issue of food security and is committed to achieving the 'zero hunger' goal as part of the Sustainable Development Goals by 2030 [10].

After analyzing preliminary studies on climate change, it is evident that CO_2 emission is an obvious problem for the entire world, including Pakistan. Various researches were conducted on this topic in the Pakistani context [11]-[15]. However, such studies used symmetric models that are not rich enough to provide accurate and reliable estimations. Alternatively, the non-linearity gained considerable attention. Anoruo [16] pointed out the difference between asymmetric and symmetric models and stated that linear models are inefficient in the analysis of variables' while asymmetric models provide efficient performance over time. Hence, this research by paying attention to the environmental changes and asymmetries is distinct from past studies and has a significant contribution. The authors applied a Non-linear Autoregressive Distributed Lag (NARDL)

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approach to check the long and short term relationships and asymmetries between agriculture, energy consumption, food security, and CO_2 emission in Pakistan.

The current study captures the positive and negative shocks of the agriculture sector on the CO_2 discharge, as Pakistan faced intensified threats from environmental changes because of its overreliance on the agricultural economy. Furthermore, previous studies examined the shocks of all independent variables, which may not clearly define the performance of the specific variable; therefore, this is the first attempt that considers one variable in a single period in this regard, to the best of authors' knowledge. The authors have used almost all well-known root unit tests (Augmented Dicky Fuller (ADF), Philips-Perron (PP), Kwiatkowski, Philips, Schmidt, and Shin (KPSS)), including Zivot and Andrews (Z and A) structural break test to check the integration level and breaks in the variables. To ensure the robustness of data, we applied different diagnostic tests in the shape of Lagrange Multiplier (LM), Jarque-Bera (J-B), and Breusch-Pagan-Godfrey (B-P-G) test. The pairwise granger causality test was carried out to check the correlation among the variables.

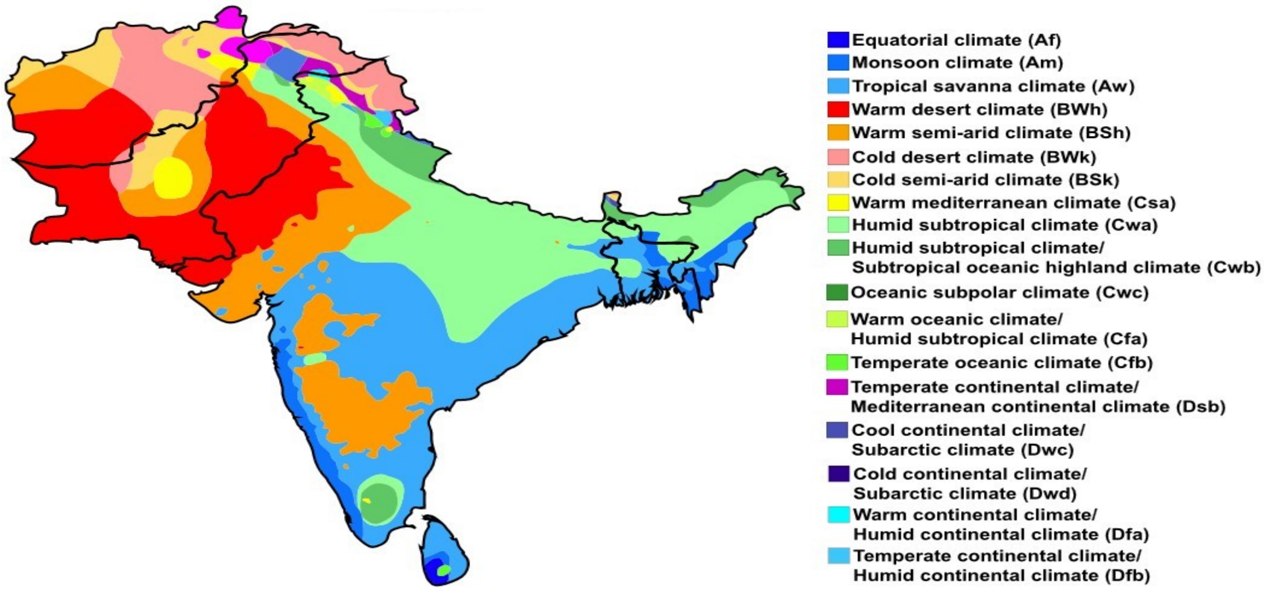

Fig. 1. Climate classification.
Source: World Köppen Classification (2016).

2. LITERATURE REVIEW

This literature provides an escalating overview of studies in various scenarios of the variables of our interest. In Pakistan, numerous scholars determined CO_2 in various ways. Some of the environmental-related investigates were performed by [17]–[23]. Additionally, CO_2 emissions have been linked to agriculture, which is an important cause of environmental degradation and is also known to be a serious threat to climate change. A summary of earlier CO_2 research on agriculture, energy consumption, and food security is provided in Table 1.

Onder [34] presented the positive and negative impact of agriculture on the environment; they revealed that positive effects include the supply of natural life, increasing oxygen production through photosynthesis in the atmosphere, whereas adverse effects arise from the overuse of pesticide and chemical fertilizers. In Italy, Coderoni and Esposti [29] scrutinize the link between agriculture and CO_2 in the long-run. The outcomes divulged that agriculture has a profound impact on CO_2. Similarly, Stolze [35] stated that when the authors applied organic structure, agriculture has a strong beneficial effect on the environment. It is generally recognized that ecological circumstances such as heat, humidity, and floods have a dramatic impact on agriculture. As a result, agriculture has a profound effect on the environment by producing CO_2 through the direct and indirect use of fuel and energy [36].

Furthermore, energy plays a pivotal role in sustainable development, and its usage will rise by 56% [8]. These increases in energy use will affect environmental pollution. Consequently, several studies were conducted to check the relation between energy consumption and CO_2 [37]-[39]. These studies revealed that energy consumption has a dominant and profound effect on CO_2. Rahman and Ahmad [40], and Anser [41] evaluated the impact of energy consumption on CO_2 for Pakistan, and their outcomes endorsed a profound effect on the growth of CO_2. Salahuddin and Gow [42] utilized panel cointegration and PMG estimator to review the relationship between energy usage and CO_2 from 1980 to 2012 for the Gulf Cooperation Council countries. The empirical analysis discovered the similar effect of energy consumption on CO_2. Ssali [43] used ADRL methodology to examine the relationship between economic growth, FDI, energy consumption, and CO_2 from 1980 to 2014 for sub-Saharan countries. Their results show bidirectional causality for the short term and unidirectional causality for the long run from energy consumption to CO_2. A similar correlation between energy consumption and CO_2 was examined in [44] for Southeast Asia and found an essential link among CO_2 and energy consumption. [45] investigated the relationship between energy consumption and CO_2 by using time series analysis for turkey, and indicated a significant positive effect of energy consumption on CO_2.

Table 1. A summary of earlier CO_2 research.

Authors	Methodology	Period	Countries	Findings
[24]	ARDL	1990-2014	Pakistan	Forest area and REC decrease the CO_2, while agriculture significantly contributes to CO_2 emission
[25]	NARDL	1990-2014	KSA	A positive and adverse shock to REC had an inverse effect on CE
[26]	EKC	1970-2016	Pakistan	The negative effect of FD on CO_2 reveals efficacious energy management
[8]	NARDL	1975-2016	Pakistan	Insignificant positive impact among agriculture and CO_2 while trade openness, population have a significant negative relation
[27]	NARDL	1991-2015	China	A significant negative link between environmental regulation and CO_2
[28]	PMG	1979-2012	55 middle-income countries	Trade openness and urbanization has a negative effect on CO_2
[8]	ARDL	1987-2017	Pakistan	CA, EC, FO, GDP have a positively significant link with CO_2
[29]	Panel VAR model	2000-2016	Asian countries	Biofuel prices on food prices have a significant relation
[30]	ARDL	1971 to 2017	Kuwait	EC increases CO_2 emission
[31]	Panel fix effect model	1980-2017	East Asian countries	urbanization, EG, and trade openness considerably increase in CO_2 emission
[13]	EKC, ARDL	1975-2014	Pakistan	Economic globalization, political globalization, and social globalization increase CO_2
[32]	EKC	1990-2014	BRICS	Agriculture has an unfriendly impact on CO_2
[33]	NARDL	1976-2014	Thailand	EG, EC, CF, TO have a significant link with CO_2

Moreover, the population of the world is predicted to reach 9 billion by 2040, out of which 25% belong to South Asian countries [46]. Some scholars observed the population growth impact on the CO_2 emission and narrated that overpopulation increases food insecurity and environmental degradation [47]-[50]. According to Shi [51], carbon emissions are caused by increasing population growth. Another research carried out by Birdsall [52] confirmed that high population growth increases the CO_2. The overpopulation has a detrimental effect on the environment.

After the perceptive summary of agriculture, energy consumption, and food security literature about climatic change, CO_2 is a global problem, and several scholars and analysts undertaking their analysis on this topic. Consequently, CO_2 emission is determined by the integration of many other variables such as economic growth, financial development, GDP per capita, renewable energy consumption, population growth, and poverty [22], [53]-[66]. Listed studies are categorized into different sections (positive and negative), each for the dimensions and scope of the CO_2 variables.

A comprehensive review of the vast range of CO_2 related studies showed that most of the researchers applied linear models to analyze the relationships. Po and Huang [67] stated the failure of linear models to evaluate the short-run uncertainty effect. Similarly, based on the symmetric and asymmetric model's relationship, Anoru [18] claimed that, in estimating the disproportionate behavior of variables over time, the linear model shows inefficiencies. Bildirici and Turkmen [68] also confirmed that asymmetries had far more interpretative power than the linear models. Hence, Shin, Yu (2014) developed a NARDL model due to the technical limitations associated with linear modeling. The NARDL model was employed in [40], [69], [70] and many others in their analysis. The NARDL model is becoming famous and gained popularity; therefore, we used the same methodology to examine the asymmetric impact of agriculture, energy consumption, and food security on CO_2 emission in Pakistan. In addition, the present study explores the agricultural sector's positive and negative shocks on CO_2 emissions, as Pakistan encountered increased environmental threats due to its over-reliance on the agrarian economy. Figure 2 depicts the conceptual framework of the study.

2. MATERIALS AND METHODS

As previously stated, literature is dominated by linear models, and most of the reviewed studies explained the association between CO_2 and its determinants by using the same methodology. Many researchers illustrated the short-term and long-term co-integration models among predictor and outcome variables but ignored the asymmetric relationship for CO_2 simulation.

This research, therefore, used asymmetric ARDL methods to fill this gap and analyze the impact of agriculture, energy usage, and food security on CO_2 emissions in Pakistan from 1970 to 2019. All the data were acquired from World Development Indicators (WDI), and the definitions of the variables are elaborated in Table 2.

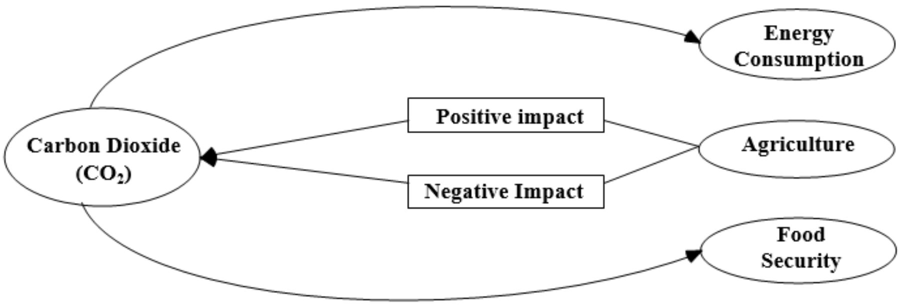

Fig. 2. Conceptual framework.

Table 2. Variables descriptions.

Variables	Sign	Definitions	Units
Carbon emission	CO_2	Carbon dioxide emission is associated with fossil energy combustion; sources include coal and oil.	Metric tons per capita
Agriculture value-added	AG	The art, science, or occupation is dealing with agricultural land, crop and livestock feeding, breeding.	% of GDP
Energy consumption	EN	The amount of energy utilized by individuals, companies, and nations.	kg of oil equivalent per capita
Food security	FS	Food security is that when a full and nutritious meal is received physically and economically, thus fulfilling the nutritional requirements for a healthy and stable living.	Population in total

2.1 Econometric Model

To examine the long-term effects of agriculture, food security, energy consumption on CO_2 emissions in Pakistan, the authors have derived the following equation from [19], [71];

$$CO_{2t} = \beta_o + \beta_1(AG_t) + \beta_2(EN_t) + \beta_3(FS_t) + \mu_t \quad (1)$$

where CO_2, AG, EN, and FS represent carbon emission, agriculture value-added, energy consumption, and food security, respectively. Long-run parameters are denoted with β_1, β_2, and β_3; while μ_t express the error term. A model named as an asymmetric ARDL developed by Shin [1] determined the short and long-run asymmetric effects while having partial sums of both positive and negative decompositions. The NARDL method has many strengths in contrast to other traditional co-integration approaches. First of all, even in the presence of a small sample size, it works smoothly. Secondly, NARDL doesn’t require stationary test compulsion [70]. Thirdly, the NARDL method can be applied, if the level of cointegration of the variables is steady at the level form I(0) or first difference form I(1) or fractionally integrated. However, it could not be utilized in the model used to have any I(2) variables. The current study utilized the NARDL methodology because of its potential to examine the short- and long-term asymmetries between the proposed variables. In this regard, NARDL bound test developed by Shin [1], was exercised. Equation 1 manages to provide only long-run results for a given model; therefore, it has to be updated to deal with short-run effects and for error correction mechanism. Thus, the following Equation 1 was defined by incorporating Pesaran [72] bound test and considering the method of error correction:

$$\Delta CO_{2t} = \theta + \sum_{K=1}^{P1} \emptyset_K \Delta CO_{2t-k} + \sum_{K=1}^{P2} \emptyset_K \Delta EN_{t-k} + \sum_{K=1}^{P3} \emptyset_K \Delta FS_{t-k} + \sum_{K=1}^{P4} \emptyset_K \Delta AG_{t-k} + \gamma_1 CO_{2t-1} + \gamma_2 EN_{t-1} + \gamma_3 FS_{t-1} + \gamma_4 AG_{t-1} + \lambda EC_{t-i} + \varepsilon_t \quad (2)$$

Equation 2 is consistent with the Engle and Granger [73] process; however, the authors substituted the lag of error term of Equation 1 with its proxy, which is a linear mixture of the lagged level variable. The benefit of Equation 1 over Engle and Granger (1987) is that we can test the results of both short and long-run estimations. $\gamma_1, \gamma_2, \gamma_3$, and γ_4 Signify long-term coefficients, while the representation of short-term parameters is the first difference variables in Equation 2. In addition, ascertaining long-run causality is essential for the reliability of the long-run coefficients. Pesaran [72] recommended the use of bound F-statistics test to verify the co-integration occurrence among CO_2 emissions and its factors. In Equation 1, it is assumed that all the independent variables symmetrically impact the corresponding variable; conversely, our primary emphasis in this study is to ascertain the asymmetric impact of agriculture on CO_2 in Pakistan. Accordingly, the chosen variables are turn into negative and positive components to observe the asymmetric effect on the dependent variable. The asymmetric regression $x_t = \delta^t y_t^+ + \delta^- y_t^- + \mu_t$, where y_t signifies independent variables and $\delta^+ and\ \delta^-$ denotes coefficients of the long run as:

$$y_t = y_o + y_t^+ + y_t^- \quad (3)$$

Where $y^+ and\ y^-$ the repressors are disintegrated as negative and positive adjustments in partial numbers, and following Equations 4 and 5 are partial quantities of negative-positive changes in agriculture.

$$AG^+ = \sum_{i=1}^{t} \Delta AG_i^+ = \sum_{i=1}^{t} max\,(\Delta AG_i, 0) \quad (4)$$

$$AG^- = \sum_{i=1}^{t} \Delta AG_i^- = \sum_{i=1}^{t} min\left(\Delta AG_{i,} 0\right) \quad (5)$$

For asymmetric ARDL equation, put positive and negative series (4 and 5) in Equation 2, while NARDL is expressed in Equation 6.

$$\Delta CO_{2t} = \theta + \sum_{K=1}^{P1} \emptyset_K \Delta CO_{2t-k} + \sum_{K=1}^{P2} \emptyset_K \Delta AG_{t-k}^+ + \sum_{K=1}^{P3} \emptyset_K \Delta AG_{t-k}^- + \sum_{K=1}^{P4} \emptyset_K \Delta EN_{t-k} + \sum_{K=1}^{P5} \emptyset_K \Delta FS_{t-k} + \gamma_1 CO_{2t-1} + \gamma_2 AG_{t-1}^+ + \gamma_3 AG_{t-1}^- + \gamma_4 EN_{t-1} + \gamma_5 FS_{t-1} + \mu_t \quad (6)$$

Consequently, Equation 6 was tested to choose the appropriate ARDL criteria by following a general to a specific procedure. Various theoretical researches have adopted the general-to-specific protocol for the final ARDL structure [1], [74]. Moreover, structural break tests to avoid any disruption that could fail to refute the null hypothesis of no long-run cointegration relationship were performed. In addition, several events happened over the time of our large sample size (1970–2019), which may induce breaks in the concerned variables, so the Bai and Perron multiple breakpoint analysis was utilized.

3. RESULTS AND DISCUSSION

Before establishing the relationship between agriculture, energy consumption, food security, and CO_2 emissions through NARDL, the authors performed various unit root tests to verify the variables' stationarity.

3.1 Unit Root Test Results

The NARDL methodology can be applied if the measured variables are stationary at I(0) or I(1) or the combination of two. Consequently, NARDL cannot be used when there are any I(2) variables [63]; hence, it needs to be verified that no such variables are included. To check the existence of I(2), and level of integration of the variables, we utilized renowned unit root tests (ADF, PP, and KPSS) and summarized their results in Table 3. It is evident from the outcomes that none of the I(2) variables are included. Likewise, the findings of the Zivot-Andrews structural break unit root test are pasted in Table 4, which implies a unit root problem for certain variables in the level form. However, our variables are measured to be stable at the optimal level, even though structural variations remained present.

All the variables expressed non-stationarity at the level in the existence of structural breaks in 2007 (CO_2 emission), 2009 (agriculture value-added), 2002 (energy consumption), and 1998 (food security).

3.2 Summary Statistics and Correlation Matrix

Table 5 exhibited the findings of summary statistics and correlation matrix.

The outcomes of descriptive statistics stated that all the variables were normally distributed, which was supported by the standard deviation, probability, and Jarque-Bera statistics values. Similarly, the results of the correlation matrix indicate a significant positive correlation between energy consumption, food security, and CO_2 emission, while agriculture has a significant negative relationship with CO_2.

3.3 Bound Test

Table 6 represent F-statistics bound test results in a nonlinear specification. The F-statistic value endorses the cointegration relation between agriculture, energy consumption, food security, and CO_2 as the estimated value (4.149) exceeds the upper bound tabulated value at a 5% level of significance. The selection of a given lag order was based on the Akaike Information Criterion (AIC).

Table 3. Unit root tests.

Tests	CO_2	AG	EN	FS
Augmented Dickey-Fuller test (ADF)				
Level	-0.580	-2.031	-1.655	-3.452*
First difference	-3.661*	-5.326*	-5.312*	-1.668
Phillips–Perron test (PP)				
Level	-0.509	-2.044	-1.562	-2.036*
First difference	-6.753*	-4.303*	-3.157*	-0.463
Kwiatkowski–Phillips–Schmidt–Shin test (KPSS)				
Level	0.682*	0.658*	0.711*	0.735*
First difference	0.229	0.221	0.233***	0.552**

Note: *, **, *** signifies 1%, 5% and 10% level of significance.

Table 4. Results of the Zivot-Andrews unit root test.

	Level		1st Difference	
Variables	t-statistic	Year of break	t-statistic	Year of break
CO_2	-0.431	2007	-4.5131*	1990
AG	-0.224	2009	-5.2173*	2011
EN	-1.6729	2002	-3.3110*	2010
FS	-0.2800	1998	-6.7823**	1999

Note: * and ** indicates a 1% and 5% level of significance, respectively.

Table 5. Descriptive statistics and correlation matrix.

	CO_2	AG	EN	FS
Mean	-0.6064	2.2411	5.8821	11.6810
Median	-0.3128	1.6644	4.0112	14.5012
Maximum	-0.0105	1.3221	6.3615	16.0670
Minimum	-1.2051	2.0246	3.4290	17.8041
Std. Dev.	0.4071	0.4134	0.1856	0.2899
Skewness	-0.2841	0.5511	-0.4122	-0.1197
Kurtosis	1.6805	1.4801	1.7731	1.7162
Jarque-Bera	2.5558	2.5931	3.2140	2.2209
Probability	0.1827	0.2256	0.2012	0.2572
CO_2	1			
AG	-0.7011* (0.0000)	1		
EN	0.6943* (0.0010)	-0.7209* (0.0133)	1	
FS	0.6505* (0.0004)	-0.6953* (0.0003)	0.7411* (0.0002)	1

*, ** denotes a significant level at 1% and 5% levels, respectively.

Table 6. Bounds test results in nonlinear specification

Test Statistics	Value	
F-Statistics	4.210**	
	Critical Bounds Values	
Significance level	Level	1st Difference
10%	2.45	3.52
5%	2.86	4.01
1%	3.74	5.06

* indicates a level of significance 5%.

3.4 Long-run and Short-run Results

The core objective of Table 7 is to empirically demonstrate the long run and short-run effects of all the variables regarding positive and negative shocks. The positive shock response of agriculture indicates an insignificant association between agriculture and CO_2. In contrast, adverse shocks in agriculture have a substantial negative effect on CO_2 emissions, which illustrates that it will decrease CO_2 emission in Pakistan. Agriculture holds quite a lead role in the economic development of Pakistan, and the current agricultural activities are practicing using conventional methods. Farmers utilized various chemicals and toxic pesticides for early growth in these traditional farming practices, which could be the reason for excessive CO_2 production in Pakistan [75]. Agriculture results are shocking and unprecedented, but as stated earlier, further contraction in the agricultural production level would pose food security complications for the rapidly increasing population. Furthermore, various studies show a favorable relationship between agriculture and CO_2 emissions [24], [76]. Agriculture improves Pakistan's economy through multiple channels, i.e., grow budget revenues, strengthens the trade balance, and significantly increases household income, which eventually affects the economy positively [77].

Table 7. Estimated short-run and long-run coefficients of NARDL model.

Variables	Coefficient	t-statistic	P-value
Long-run coefficients			
AG+	0.2101	1.0011	0.5631
AG-	-0.4130	-1.4544	0.0401
EN	1.6342	10.1230	0.0220
FS	0.0213	0.3522	0.0104
C	-9.5033	-3.6750	0.0001
Asymmetric ARDL (Short-run)			
CO_2 (-1)	0.0561	0.6943	0.4433
AG^+	0.0311	0.5800	0.2690
AG^-	-0.3325	-1.7022	0.0102
AG^-(-1)	0.0341	0.6250	0.5413
EN	1.3772	5.02110	0.0001
EN (-1)	0.5420	0.7280	0.5502
FS	6.8802	3.6010	0.0003
FS (-1)	-8.0230	-3.4033	0.0000
C	-8.6371	-1.7755	0.0000
$D_{(2008)}$	0.0719	2.1251	0.0401
ΔAG (-2)	0.0618	0.2036	0.3168
ΔEN (-1)	1.1830	2.5799	0.0006
ΔFS (-1)	-0.1552	-0.3452	0.4502
ECT (-1)	-0.5641	-5.0123	0.0000
R-squared	0.9753		
Adj.R-squared	0.9874		
F-statistic	1520.112		
Probability	0.0000		
D-W	2.0622		

Note: D (2008) represents a structural break in the data set. Δ denotes the difference operator. D-W signifies the Durbin-Watson statistic for autocorrelation

The EN's findings indicate a considerable positive impact on CO_2 emission with a coefficient value of 1.63. The reported result implies that the rise of energy consumption deteriorates environmental conditions by raising CO_2 discharge. The findings of energy use support the conclusions of preceding researchers [78]-[80]. Their studies also established a substantial and decisive relationship between CO_2 and energy use. The findings also suggest that energy use is an influential element in affecting the CO_2. Furthermore, Pakistan is a rapidly developing middle-class state that consumed fossil fuel energy instead of renewables. Fossil-based energy consumption further destroys the natural environment. However, the carbon-free energy options, such as hydro, nuclear, and wind, can assist in boosting the sustainability of the atmosphere.

Similarly, the FS coefficient also has a significant positive impact on CO_2 emission. The results explain that a 1% growth in food security (population) will generate 0.02% CO_2 emissions in the environment. Although the FS coefficient is quite low, it is still an alarming indication for a country like Pakistan, which has the second biggest populace in South Asia [81]. This phenomenal rate of population growth will make Pakistan the fourth most populated nation in the world, by exceeding Indonesia and Brazil in 2050 [82]. The short-run parameter estimations produce a similar effect as of the long-run but with different coefficient values. Additionally, the structural break results are also narrated in Table 7, which shows a significant break (2008) in the data series. The dummy variable was incorporated in the NARDL estimation procedure, where 0 inserted before the break year date and 1 for the following years. The break may be associated with the global financial crises.

3.5 Diagnostic Inspection

To verify the cointegration assessment, various diagnostic tests were performed. Table 8 presented the findings of serial correlation, normality, and heteroscedasticity analysis. The stated model successfully exceeded in all tests owing to the absence of normality, autocorrelation, and heteroscedasticity at a 5% level of significance.

3.6 Structural Stability Test

The structural stability of the NARDL model is ensured with CUSUM, and CUSUMSQ approaches. This method states that higher and lower bounds must be within the critical restraints; otherwise, the model is not consistent [83]. Accordingly, both graphs (Figure 3) show that the blue lines are within the essential boundaries. Therefore, the model is accurate and safe to forecast the inferences.

Table 8. Diagnostic inspection.

Diagnostic tests	Coefficient	p-value	Decision
J-B	0.278	0.681	Residuals are normal distributed
LM	0.586	0.282	No serial correlation
B-P-G	1.032	0.564	No heteroscedasticity

Notes: LM, J-B, and B-P-G are the Lagrange Multiplier, Jarque-Bera, and Breusch-Pagan-Godfrey tests, respectively, whereas CUSUM and CUSUMQ specify Cumulative Sum of Recursive Residuals and Cumulative Sum of Squares of Recursive Residuals test for structural stability.

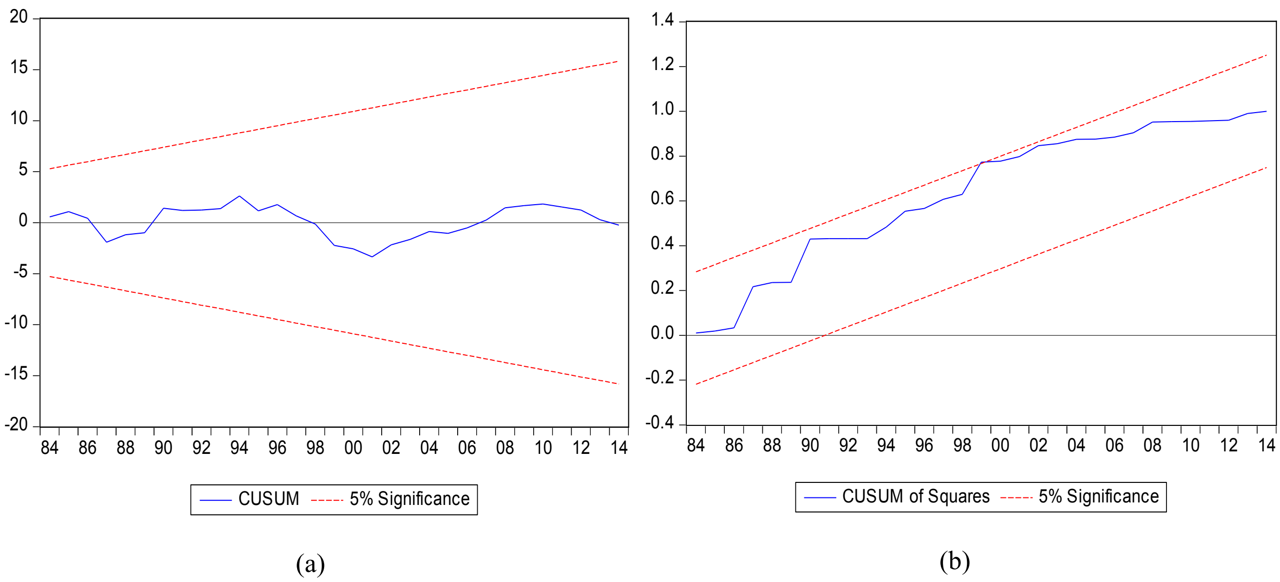

Fig. 3. (a) Cumulative sum of recursive residuals, and (b) Cumulative sum of squares of recursive residuals.

3.7 Pair-wise Granger Causality Test

The current research also used a pairwise granger causality test to evaluate the causality direction among the variables. There are three kinds of classifications in the Granger causality approach, for instance, bidirectional, unidirectional and, no causality. The granger causality results are shown in Table 9.

The results illustrate that the agriculture granger causes CO_2 by rejecting the null hypothesis at a 1% level of significance. While CO_2 does not granger cause agriculture, which implies that the assumption of CO_2 does not granger cause agriculture is not rejected. There is an indication of unidirectional causality from AG→CO_2. The null hypothesis that energy consumption does not granger causes CO_2 is rejected at a 5% significance level. However, CO_2 does not granger cause energy consumption, which failed to reject the null hypothesis; hence, there is found a unidirectional causality from EN→CO_2. In addition, the null hypothesis that food security (population) does not granger cause CO_2 is not rejected. CO_2 does granger cause food security by rejecting the null hypothesis that CO_2 does not granger cause food security; hence, there exists a unidirectional causality running from CO_2→FS at a 1% significance level. Lastly, the dynamic multiplier graph (Figure 4) indicates that the adverse shocks of agriculture have more effect than the positive results.

Table 9. Granger causality results.

Null Hypothesis	F-statistic	Probability
AG does not Granger Cause CO_2	3.3112	0.0070
CO_2 does not Granger Cause AG	1.5798	0.2507
EN does not Granger Cause CO_2	2.2033	0.0231
CO_2 does not Granger Cause EN	1.4402	0.3502
FS does not Granger Cause CO_2	0.6844	0.4532
CO_2 does not Granger Cause FS	1.8725	0.0113

Source: Authors' calculation.

5. CONCLUSION AND POLICY IMPLICATIONS

It is confirmed on the basis of the above estimations that CO_2 is a significant contributor in agriculture, energy consumption, and food security. The primary purpose of the present study is to examine the asymmetric association among the variables mentioned above in Pakistan. Several unit tests (ADF, PP, KPSS, and Z and A) has been used to measure the stationary existence and structural breaks in the data to accomplish the specified objective. Moreover, the asymmetric ARDL cointegration method has been used, which has an essential function for simultaneously detecting short- and long-term patterns within the predictor variables. The current research further explores the positive and negative shocks of agriculture value-added on CO_2 emissions.

The results of the NARDL model established the long-term cointegration between agriculture, energy consumption, and food security on CO_2 emissions of Pakistan. The agriculture value-added in the long-term specified that positive shocks have an insignificant impact, while adverse shocks have a significant negative impact on the CO_2 emission of Pakistan. The energy consumption and food security in the long-term have substantial positive effects on CO_2 in Pakistan. To examine the causal direction of all research variables, a pair-wise Granger causality test has been implemented. The granger causality results revealed that there is unidirectional causality from AG→CO_2, EN→CO_2, and CO_2→FS.

Based on these results, some key policy arises, which indicates a powerful connection between Pakistan's agricultural ecosystem and emission.

For the sake of sustainable agriculture and to reduce pollution, it is necessary to avoid excessive use of fertilizers and pesticides and put emphasis on green production. Furthermore, Pakistan is included among the countries severely affected by CO_2 emission; therefore, the environmental risks need to be addressed seriously. The government should reduce its dependence on fossil energy and raise renewable energy investments. Energy consumption should be rehabilitated in the northern regions of the country, as most of the people cut forests for their daily heating and cooking needs, which degrade the environment. In addition, Pakistan has faced a severe food insecurity problem. To improve the country's efforts to achieve food security, the investors must combine organic and conventional food measures without infecting the agricultural environment. Addressing the current and future food insecurity issues, eco-technologies need to be developed at a low price to assure sustainable food production. Therefore, The Implementation of climate and energy policies will also limit carbon dioxide emissions and protect our environment from emissions, thus saving millions of lives from natural disasters.

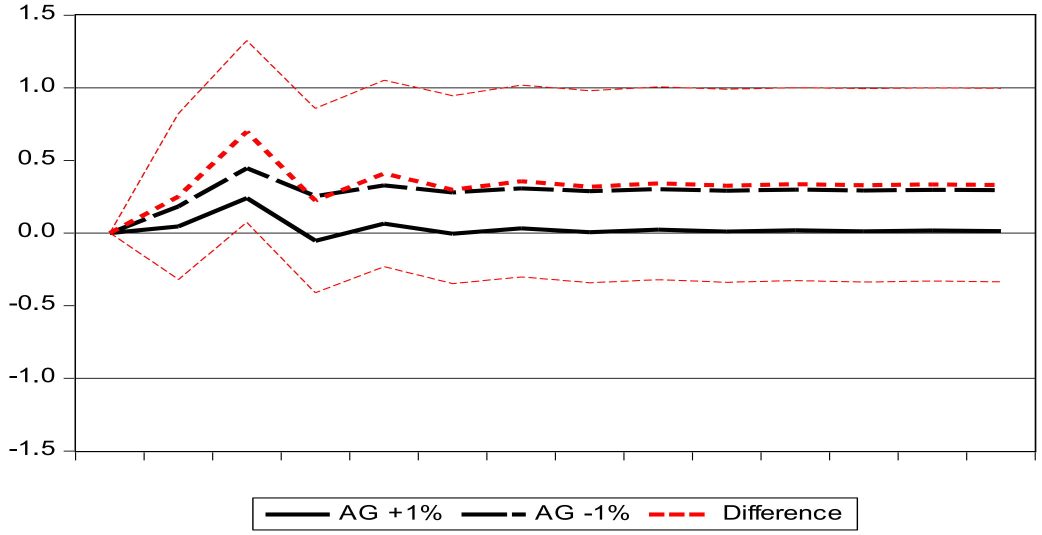

Fig. 4. Agriculture value-added dynamic multipliers.
Note: The solid black line indicates the positive impact of agriculture value-added. Blackline in dots displays a negative effect of agriculture value-added. The strong dotted red line shows an asymmetry, while thin red lines represent critical bounds.

5. LIMITATIONS AND FUTURE DIRECTIONS

This work adds value to future research, in which scholars can use our methodology to raise awareness of the interrelationships between agriculture, energy use, food security and CO_2 emission in countries other than Pakistan. In addition, the existing NARDL method may be replaced with ARDL or Environmental Kuznets Curve or other econometrics techniques. The ecological variations can be evaluated through other related variables, *i.e.,* financial development or economic growth, which may provide better understandings. Lastly, the present study utilized data set from 1970-2019; however, future studies may use different and more recent set of observations to get better outcomes.

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