Asian Journal of Agriculture and Rural Development
Volume 12, Issue 3 (2022): 192-200.

http://www.aessweb.com/journals/5005

CLIMATE CHANGE FACTORS' IMPACT ON THE EGYPTIAN AGRICULTURAL SECTOR

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Article History
Received: 28 April 2022
Revised: 22 July 2022
Accepted: 5 August 2022
Published: 29 August 2022

Keywords
Climate change
Carbon dioxide
Temperature
Rainfall
Agriculture GDP
Unit root tests
ARDL
Bound tests.

ABSTRACT
Climate change is the greatest threat to agriculture and food security, particularly in developing countries. Climate change occurs as CO_2 levels in the atmosphere rise, causing changes in wind patterns and rainfall and rising temperatures. This study assumes that climate change will have a long-run impact on Egypt's agricultural sector. So, an autoregressive distributed lag model (ARDL) was applied to examine the effects of climate change factors and other economic factors on Egyptian agricultural GDP in the short and long run from 1990 to 2020. The findings indicate that climate change factors have a long-run impact on Egypt's agricultural sector. In the long run, CO_2 is the primary cause of Egypt's increasing temperatures. In the short run, climate change occurs because CO_2 levels in the atmosphere increase, resulting in global warming, storms, floods, and rising sea levels. The result is that rising temperatures have reduced agricultural GDP.

Contribution/Originality: The present study is, according to the best of the authors' knowledge, the first to examine the short- and long-run impacts of climatic factors (temperature, CO_2, and rainfall) and economic variables on GDP in Egypt using the ARDL method.

DOI: 10.55493/5005.v12i3.4600
ISSN(P): 2304-1455/ ISSN(E): 2224-4433

How to cite: Zainab Shawky El-Khalifa --- Hoda Farouk Zahran --- Ahmed Ayoub (2022). Climate Change Factors' Impact on the Egyptian Agricultural Sector. *Asian Journal of Agriculture and Rural Development*, 12(3), 192-200. 10.55493/5005.v12i3.4600

1. INTRODUCTION

Climate change is a serious threat to agriculture and food security, particularly in many developing countries (Chandio, Ahsan, & Fang, 2020; Kilicaslan & Dumrul, 2017). Climate change also has an impact on agriculture as it results in changes to rainfall and wind patterns, rising temperatures, decreased crop productivity, and changes in planting and harvest dates (El-khalifa, Zahran, & ElSheikh, 2018; Rosegrant et al., 2008). In addition, agriculture plays a critical role in ensuring food security. For the majority of rural communities, it represents a significant source of income (Chandio et al., 2020). Furthermore, the agriculture sector contributes to increasing GDP by supplying raw materials, creating jobs in the industrial sector, and providing foreign exchange that contributes to economic development (MALR, 2021). To accommodate the rapid population growth, agriculture production should be expanded. As a result, Egypt has pursued two main strategies: the reclamation of vast desert areas to become productive land and intensive cultivation of existing productive land using high-tech management techniques (Abdel-Rahman, Afifi, & Scopa, 2021). Climate change is caused by a rise in carbon dioxide (CO_2) levels in the atmosphere (Kilicaslan & Dumrul, 2017). CO_2 is the main greenhouse gas (GHG) emitted by human activities, including the use of fossil fuels for energy, such as coal and oil, as well as transportation, electricity, and industry (Rahim & Puay, 2017; Rehman, Ozturk, & Zhang, 2019). CO_2 emissions account for more than half of GHG emissions, which may be linked to significant climate change impacts such as global warming, storms, floods, and rising sea levels (Yang, Ali, Nazir, Ullah, & Qayyum, 2020). According to the Intergovernmental Panel on Climate Change (IPCC), CO_2 is the primary cause of global warming and will raise average global temperatures by about 0.3°C per decade over the next century (El-khalifa, El-Sheikh, & Zahran, 2020; Kim, 2012). Likewise, according to AR5 Climate Change (2014), if no further mitigation efforts are made, the average global temperature will have risen by 3.5°C by 2100. Carbon dioxide emissions have thus emerged as an economic and environmental challenge on a global scale (Garidzirai, 2020). Moreover, increasing temperatures cause changes in the rainfall system. Rainfall increases can cause soil moisture levels to rise, which is of benefit to semi-arid soils but can exacerbate problems in others. On the other hand, a decrease in rainfall may cause a water crisis in the agricultural sector (Rahim & Puay, 2017). The agriculture sector itself contributes 14%–30% of global greenhouse gas emissions due to the use of fuel-powered agricultural equipment (Rehman et al., 2019).

Obviously, climate change may lead to significant economic losses, as is currently happening around the world; it has increased the frequency of natural disasters, such as floods, storms, and drought. Climate change is endangering food production and future food supply, especially given the world's rapid population growth and food demand (Rabbi & Tabassum, 2020; Rehman et al., 2019), which contribute to an increase in CO_2 emissions over time. Additionally, climate change will affect global agricultural commodity prices (Kilicaslan & Dumrul, 2017). Moreover, Onyeji and Fischer (1994) pointed out that global warming happens over time due to the steady accumulation of greenhouse gases, particularly CO_2, in the atmosphere, which is expected to reach approximately 660 parts per million (ppm) by the year 2030. In 2020, the global average CO_2 level was 412.5 ppm. Despite a 7% decrease in emissions due to COVID-19, this is the fifth highest increase in 63 years (NOAA, 2020; WMO, 2020). Climate change has already had a negative impact on Egypt's agriculture sector. It is considered one of the countries most susceptible to the potential effects of climate change (El Raey & Book, 2010). Climate change has resulted in abrupt shifts in climatic factors, such as extremely cold winters, long and extremely hot summers, and unseasonal rains. Climate change has resulted in a shortage of agricultural crops, particularly strategic crops such as wheat, maize, and rice, as well as significant water loss in arid to semiarid environments. It endangers both water and food security (EMA, 2021; MALR, 2021). The objectives of this research are twofold. First, it examines the effects of climate change factors and other economic factors on Egyptian agricultural GDP from 1990 to 2020 to assist Egyptian policymakers in predicting and preparing for the long-run effects of climate change factors on agriculture. Secondly, the study hypothesis assumes that climate change will have a long-run impact on Egypt's agricultural sector. Therefore, an autoregressive distributed lag model (ARDL) is used to verify this assumption and obtain accurate parameters. Furthermore, this study adds to the existing literature, although there is limited literature (if any) that examines the short- and long-run impacts of climatic factors (temperature, CO_2, and rainfall) and other economic variables on GDP in Egypt using the ARDL method to aid in the identification of the most important factors affecting developing countries' agricultural sectors, which have to play a role in mitigating the negative effects of global climate change. The current investigation is distinct from previous studies in this regard.

2. LITERATURE REVIEW

In Egypt, the agricultural sector contributed about 71.8% to the GDP in 2020. It is one of the most important sectors in the pursuit of economic development. Climate change's impact on agriculture is a major source of concern for economic development as climate change is a severe threat to agriculture and the food supply. In recent years, several studies conducted in various countries, such as Turkey, China, Pakistan, India, and Malaysia, have confirmed that climate change has a negative impact on all economic sectors. However, agriculture is the most susceptible to climate change. These studies concentrated on climate change for the purpose of developing policies, strategies, plans, and programs to combat climate change. Farmers should be made aware of the need to adapt to climate change by encouraging a shift toward agricultural output products that can withstand temperature increases. In China, Chandio et al. (2020) showed that climate factors such as changes in temperature and rainfall have a negative impact on agriculture, while CO_2 emissions have a positive impact. Others have reported that rainfall has a positive impact on agricultural GDP. Furthermore, many studies have applied the ARDL model to examine the effects of climate change factors on agriculture, crop yield, economic growth, and environmental sustainability in both the long run and the short run. Kilicaslan and Dumrul (2017) reported that precipitation has a positive impact on agricultural output in Turkey, whereas the effect of temperature is negative. Rahim and Puay (2017) investigated the relationship between Malaysian economic growth and climate change using the Johansen cointegration approach. Also, Alam (2013) investigated the response of agricultural output to climate change and its long-run impact on economic growth in India. Using an ARDL model, the study showed that CO_2 emitted, economic growth, and agricultural output have short- and long-run relationships. Furthermore, in Pakistan, Rehman et al. (2019) used an ARDL approach and found that cropped area, water availability, and GDP per capita had positive and significant relationships with carbon dioxide emitted, whereas the increased distribution of seeds and total food grain production had a negative relationship with carbon dioxide emitted. Also, previous research has found that climate change could cause a variety of socioeconomic issues, including poverty, decreased economic growth, unsustainable development, and health and safety concerns. Temperature and rainfall have been considered the two most significant climate change markers for agricultural output and have been shown to have an impact on agricultural GDP and income growth in some developed countries, such as the United States (Abdel-Rahman et al., 2021; Akadiri, Alola, Alola, & Nwambe, 2020; El Raey & Book, 2010; Kilicaslan & Dumrul, 2017). Likewise, some studies have been conducted to determine how CO_2 emissions affect agricultural crops, and how, on the other hand, energy consumption affects CO_2 emissions (Akadiri et al., 2020; Alam, 2013; Chandio et al., 2020; Kim., 2020; Onyeji & Fischer, 1994; Yang et al., 2020). They have confirmed that reducing CO_2 emissions is necessary to achieve long-run economic development. Climate change, in general, affects people all over the world. So all countries should be ready to deal with the long-run consequences of climate change. Using the ARDL model enables the long-run and short-run influences of climatic factors on GDP to be examined while controlling for certain variables, such as cultivated areas and agricultural investment.

3. RESEARCH METHODS & DATA SOURCES USED

Using the ARDL model, previous studies have shown that climate change forecasts negatively impact crop yield, agriculture, economic growth, and environmental sustainability in many countries. In this study, therefore, the ARDL model was used to examine the effects of climate change factors on Egypt's agricultural GDP (AGDP). The ARDL model was used to estimate relationships among variables in the short and long run using the EViews 12 program.

The ARDL is a cointegration test model that is used to solve spurious regression problems that arise when the time series of variables are non-stationary. It can be used to test cointegration, long- and short-run equilibrium relationships, as well as both levels and differences (Sarkodie & Owusu, 2020). The ARDL model was introduced by Pesaran and Shin (1999); Pesaran, Shin, and Smith (2001). It has many advantages, such as being appropriate and efficient for small data sets and when variables are integrated at levels I(0) or first difference I(1) or both, but not I(2), with no autocorrelation or heteroscedasticity (Shrestha & Bhatta, 2018). Compared to other cointegration methods, such as Engle and Granger cointegration (Engle & Granger, 1987) and Johansen and Juselius cointegration (Johansen & Juselius, 1990), they are integrated at the same order. Furthermore, once the ARDL cointegration test confirms the long-run cointegration relationship, the short-run coefficients between variables can be estimated using the ARDL error correction model (ECM) (Kilicaslan & Dumrul, 2017; Nkoro & Uko, 2016). The following formula can be used to specify the ARDL model that reflects the effect of variables on AGDP:

$$\text{Ln AGDP}_t = \beta_0 + \beta_1 \text{LnCO}_{2t} + \beta_2 \text{LnTEMP}_t + \beta_3 \text{LnRF}_t + \beta_4 \text{LnAINVET}_t + \beta_5 \text{LnCA}_t + \varepsilon_t \quad (1)$$

Where

Ln $AGDP_t$: is the natural logarithm of agricultural gross domestic product at time t.

$LnCO_{2t}$: is the natural logarithm of carbon dioxide emissions at time t.

$LnTEMP_t$: is the natural logarithm of average annual temperature at time t.

$LnRF_t$: is the natural logarithm of average annual rainfall at time t.

$LnAINVET_t$: is the natural logarithm of agricultural investment at time t.

$LnCA_t$: is the natural logarithm of cultivated area at time t.

ε_t: is the error term at time t.

$\beta_{1,2,3,4,5}$: are the parameters of the independent variables.

β_0: is the intercept term.

First, the ARDL model investigates the existence of long-run cointegration between the variables under consideration. The ARDL model is defined by the equation below:

$$\triangle \text{Ln AGDP}_t = \alpha_0 + \sum_{k=1}^{\rho} \alpha_{1k}\, \Delta\text{LnAGDP}_{t-k} + \sum_{k=0}^{\rho} \alpha_{2k}\, \Delta\text{LnCO}_{2t-k} + \sum_{k=0}^{\rho} \alpha_{3k}\, \Delta\text{LnTEMP}_{t-k} + \sum_{k=0}^{\rho} \alpha_{4k}\, \Delta\text{LnRF}_{t-k} + \sum_{k=0}^{\rho} \alpha_{5k}\, \Delta\text{LnAINVEST}_{t-k} + \sum_{k=0}^{\rho} \alpha_{6k}\, \Delta\text{LnCA}_{t-k} + \beta_1\text{Ln AGDP}_{t-1} + \beta_2 \text{LnCO}_{2t-1} + \beta_3 \text{LnTEMP}_{t-1} + \beta_4\text{LnRF}_{t-1} + \beta_5\text{LnAINVET}_{t-1} + \beta_6\text{LnCA}_{t-1} + \varepsilon_t \quad (2)$$

Where α_0 represents the intercept, α_1, α_2, α_3, α_4, α_5, and α_6 represent the short-run relationships, β_1, β_2, β_3, β_4, β_5, and β_6 represent the long-run relationships, ρ indicates the lag order, △ denotes the first difference operator, t-1 represents time lag, and εt indicates the error term. The F-Bound test is used to evaluate a long-run relationship. The null hypothesis H_0 means that there is no cointegration between Ln AGDP and the variables in the long run, whereas the alternative hypothesis H_1 means that there is cointegration between Ln AGDP and the variables in the long run. Following Narayan (2005) and Pesaran et al. (2001), the calculated F-statistic is compared to critical values at upper bound I(1) and lower bound I(0). If the calculated F-statistic (or t-statistic) exceeds critical values, H_0 is rejected, indicating that there is a long-run cointegration relationship between the variables; however, if the calculated F-statistic (or t-statistic) does not exceed critical values, H_1 is rejected, indicating that there is no cointegration. If the calculated F-statistic (or t-statistic) lies between the lower and upper bounds, the cointegration between the variables is inconclusive. Second, after the bound test confirms the existence of a long-run relationship, the short-run coefficients and the following ECM in the ARDL model are estimated by the next equation:

$$\triangle \text{Ln AGDP}_t = \alpha_0 + \sum_{k=1}^{\rho} \alpha_{1k}\, \Delta\text{LnAGDP}_{t-k} + \sum_{k=0}^{\rho} \alpha_{2k}\, \Delta\text{LnCO}_{2t-k} + \sum_{k=0}^{\rho} \alpha_{3k}\, \Delta\text{LnTEMP}_{t-k} + \sum_{k=0}^{\rho} \alpha_{4k}\, \Delta\text{LnRF}_{t-k}\ \sum_{k=0}^{\rho} \alpha_{5k}\, \Delta\text{LnAINVEST}_{t-k} + \sum_{k=0}^{\rho} \alpha_{6k}\, \Delta\text{LnCA}_{t-k} + \lambda\text{ECM}_{t-1} + \varepsilon_t \quad (3)$$

Where λ represents the speed of adjustment (Error Correction Model), which should be negative and statistically significant (Granger, 1988; Khan, Abdullah, & Samsudin, 2016). It measures the speed with which the dependent variables and independent variables balance from the short run to the long run. Then, using the cumulative sum and cumulative sum of squares of residuals, the stability of the ARDL model is investigated. When both CUSUM and CUSUMSQ statistically fall within critical limits at 5% significance, stability is achieved (Borensztein, De Gregorio, & Lee, 1998; Granger, 1988). Furthermore, after estimating the ARDL model, some diagnostic tests are performed to ensure the accuracy of coefficient estimates, such as the Breusch-Godfrey serial correlation (LM Test) to detect autocorrelation (Godfrey, 1978), the normality test using (Jarque & Bera, 1980), and the Breusch-Pagan-Godfrey test to detect heteroscedasticity (Engle, 1982). This study is based on published data spanning the period 1990 to 2020. The data were obtained from the Egyptian Ministry of Agriculture and Lands Reclamation, Ministry of Planning and Economic Development (MPED), the World Development Indicators (WDI) of the World Bank, the Food and

Agriculture Organization of the United Nations (FAO), www.tutiempo.net/clima, and previous studies on the subject. The data and sources are listed in Table 1.

Table 1. Data description and sources.

Data	Description	Source
AGDP	Agricultural gross domestic product (Constant 1990 L.E. million)	MPED
CO_2	Carbon dioxide emissions (metric tons per capita)	WDI
TEMP	Average annual temperature (°C)	TUTIEMPO
RF	Average annual rainfall (mm)	TUTIEMPO
AINVEST	Agricultural investment (Constant 1990 L.E. million)	MPED
CA	Cultivated area (hectares)	FAO

3. RESULTS

3.1. Descriptive Statistics of Variables

Egypt's climate is generally characterized by arid and semiarid conditions with little precipitation during the winter season. Egypt's rainfall is generally low, except for the northern coastal region. Climate change has recently contributed to an increase in rainfall. This may aid semi-arid soils in some areas by increasing soil moisture, particularly in northern Egypt, where rain-fed agriculture is prevalent. However, it has caused environmental disasters such as torrential downpours in other parts of Egypt, including Cairo, Alexandria, Giza, Dakahlia, and Aswan (EMA, 2021).

These effects have occurred as the result of rising temperatures worldwide, as well as in Egypt, as a result of higher carbon dioxide levels in the atmosphere – the cause of global warming. High temperatures also have negative impacts on the physiological processes of cultivated plants and the biological activities in the soil (El-Marsafawy, Bakr, Elbana, & El-Ramady, 2019). As a result, it is critical to investigate climatic factors and their impacts on the Egyptian agricultural sector. Agricultural gross domestic product (AGDP) is a dependent variable. During the study period, it accounted for approximately 71.3 % of GDP (real value). This means that the agriculture sector is the most important in the Egyptian economy because it provides employment, raw materials, foreign exchange, and food security (MALR, 2021). Carbon dioxide emissions, average annual temperature, average annual rainfall (climate factors), agricultural investment, and cultivated areas (economic factors) are the independent variables. They represent the vast majority of the factors that influence the agricultural sector and can help in its development. They were not stable during the study period, as shown in Figure 1. Table 2 shows the descriptive statistics of the climate change factors and economic variables that have an impact on agricultural gross domestic product (AGDP) from 1990 to 2020. Figure 1 depicts the time series plots of the study variables. Table 2 provides some indicators to explain the development of the variables over the study period. Additionally, the Jarque-Bera statistics show that all variables, except agricultural investment and cultivated area, are normally distributed. Kurtosis is moderate, and the variables are free from outliers. Furthermore, the variables are negatively skewed, except for agricultural gross domestic product, agricultural investment, and temperature, which are positively skewed.

Table 2. Descriptive statistics of variables during 1990-2020.

Variables	Mean	Median	Maximum	Minimum	Std. dev	Skewness	Kurtosis	Jarque-Bera
Ln AGDP	6.296	6.059	8.275	4.605	1.075	0.278	1.972	1.763
Ln CO_2	0.691	0.754	0.997	0.347	0.212	-0.163	1.392	3.476
Ln TEMP	3.089	3.086	3.247	2.960	0.073	0.024	2.075	1.109
Ln RF	0.626	0.747	2.355	-2.059	1.077	-0.381	2.596	0.962
Ln AINVEST	5.521	5.233	7.728	4.605	0.845	1.778	4.874	20.87^{***}
Ln CA	15.047	15.075	15.167	14.787	0.099	-1.120	3.712	7.14^{**}

Notes: Ln indicates the natural logarithmic of variables. ** and *** indicate the 5% and 1% statistical significance levels, respectively.

3.2. Stationarity Tests

The ARDL cointegration approach is adequate if the variables are stationary in the case of I(0), I(1), or a mixed integration order.

In this study, the Augmented Dickey-Fuller (ADF) (Dickey & Fuller, 1979), Phillips-Perron (PP) (Perron, 1988), and Kwiatkowski-Phillips-Schmidt-and-Shin (KPSS) (Kwiatkowski, Phillips, Schmidt, & Shin, 1992) unit root tests were used to determine the stationarity of the variables (Sarkodie & Owusu, 2020). The null hypothesis H_0 assumes that a unit root exists (the variable is non-stationary), and the alternate hypothesis H_1 assumes there is no unit root (the variable is stationary).

Table 3 shows that the variables AGDP, CO_2, TEMP, and AINVET were stable at the first difference, whereas the variables RF and CA were stable at the 0 level. This means that given the combination of I(0) and I(1) at 1% and 5% significance, all variables are stationary and the ARDL model can be used to show a strong long-run relationship among the variables in this study.

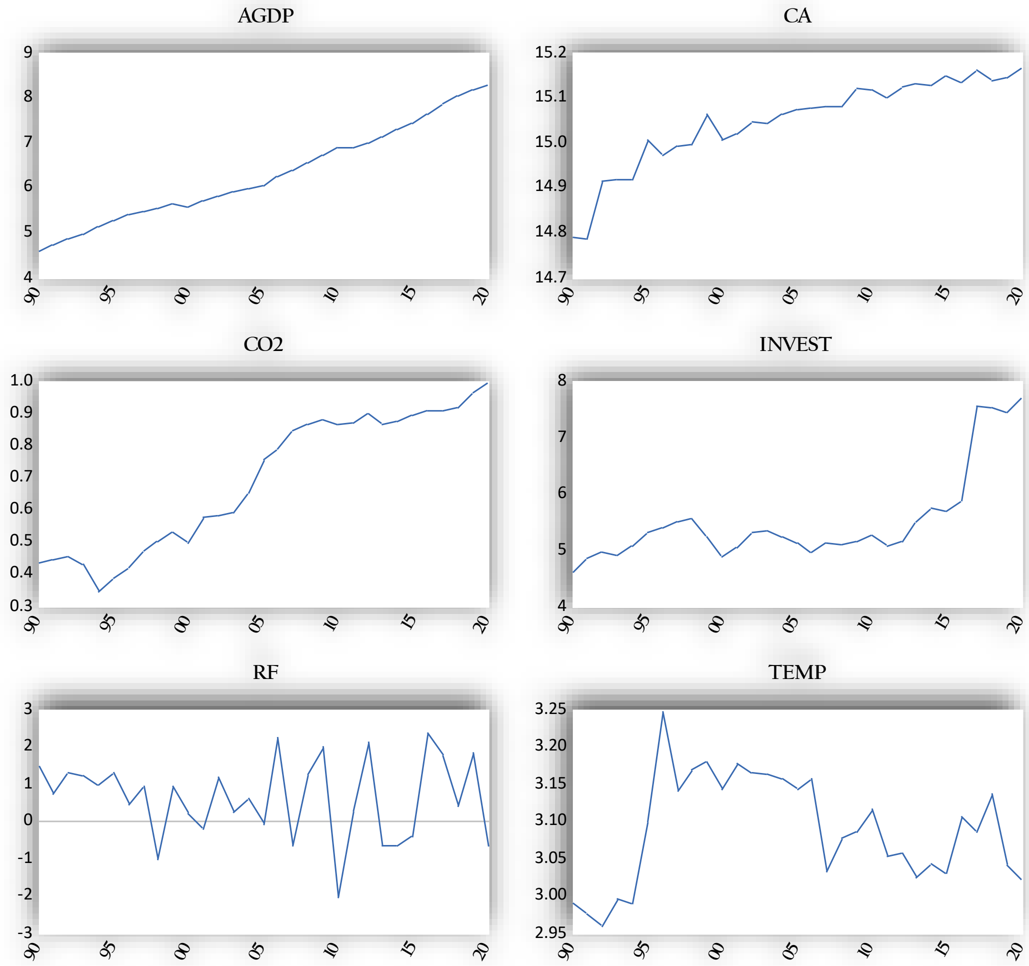

Figure 1. EViews 12 – outputs of variables time series plots.

Table 3. Results of unit root tests.

Variables	ADF	PP	KPSS	Unit root
Ln AGDP	-4.074**	-4.085**	0.0941*	At first difference
Ln CO2	-4.519***	-4.519***	0.1217*	At first difference
Ln TEMP	-6.611***	-6.627***	0.2024*	At first difference
Ln RF	-6.609***	-6.609***	0.1053*	At level
Ln AINVEST	-4.899***	-4.899***	0.2667*	At first difference
Ln CA	-3.629**	-3.871**	0.1876***	At level

Notes: The lag order selection according to the (SIC) Schwarz information criterion. ADF refers to Augmented Dickey-Fuller, PP refers to Phillips-Perron, and KPSS refers to Kwiatkowski-Phillips- Schmidt–Shin. *, **, and *** indicate the 10%, 5%, and 1% statistical significance levels.

3.3. ARDL Model & Bounds Tests

Using the optimal lag, bounds tests were applied with critical values and a p-value to test for cointegration (Sarkodie & Owusu, 2020).

The results in Table 4 show that the calculated value of the F-statistic is 6.786 and the t-statistic value is 7.259. The results of the bounds test using the selected ARDL (1,2,0,1,0,2) model thus exceed the critical values at the 1% significance level. These test results show that the variables have a long-run cointegration relationship in which Ln AGDP is the dependent variable and Ln CO_2, Ln TEMP, Ln RF, Ln AINVEST, and Ln CA are independent variables. In Table 5, the ARDL model was used to calculate the long-run and short-run results.

In the long run, the amount of CO_2 emitted has a significant and positive impact on agricultural GDP. A 1% increase in emitted CO_2 leads to an increase in agricultural GDP of 2.91%. Furthermore, the coefficient of agricultural investment in Egypt has a significant (at the 1%) and positive impact on AGDP in the long run. This indicates that a 1% increase in agricultural investment increases agricultural GDP by 0.422% in the long run. On the other hand, the negative temperature coefficient indicates that a 1% increase in temperature results in a 2.19% decrease in AGDP, a statistic that is significant at the 5% level.

In the short run, the CO_2 emitted coefficient has a positive impact that is significant at the 1% level. A 1% increase in CO_2 emitted leads to a 0.725% increase in agricultural GDP. Furthermore, the coefficients of agricultural investment and cultivated area have a positive short-run impact on AGDP that is significant at the 1% level. This indicates that a 1% increase in agricultural investment and cultivated areas contributes to a 0.105% and 0.96% increase in agricultural

GDP, respectively. In contrast, the negative temperature coefficient indicates that a 1% increase in temperature results in a 0.598% decrease in agricultural GDP, which is significant at the 1% level.

In addition, Table 5 shows the importance of the short-run results as represented in the coefficient of error correction model ECM to investigate cointegrating relationships among the variables (Jalil, Mahmood, & Idrees, 2013; Kilicaslan & Dumrul, 2017). The ECM coefficient was negative and statistically significant at 1%. This confirmed the cointegration between the variables, and the model is corrected from short-run to long-run equilibrium by -0.249. This means any disequilibria in AGDP from the previous period converge back by about 24.9% in the next period.

Table 4. ARDL bounds tests.

F-Statistic	**Significance levels**	**I(0) Bound**	**I(1) Bound**
6.786***	10%	2.26	3.35
	5%	2.62	3.79
	2.5%	2.96	4.18
	1%	3.41	4.68
t-Statistic	Significance levels	I(0) Bound	I(1) Bound
-7.259***	10%	-2.57	-3.86
	5%	-2.86	-4.19
	2.5%	-3.13	-4.46
	1%	-3.43	-4.79

Notes: *** indicates significance at the 1% level.

Table 5. ARDL model in the long and short run.

Dependent variable: Ln AGDP; selected model: ARDL (1,2,0,1,0,2)	**Long-run**	
	Coefficients	**t-statistic**
Ln CO_2	2.909	3.997***
Ln TEMP	-2.195	-2.729**
Ln RF	0.019	0.694
Ln AINVEST	0.422	10.06***
Ln CA	2.936	1.671
	Short-run	
Ln CO_2	0.725	4.255***
$\triangle$Ln TEMP	-0.598	-3.494***
Ln RF	0.005	0.702
Ln AINVEST	0.105	3.948***
$\triangle$ Ln CA	0.957	3.203***
ECM(-1)	-0.249***	

Notes: ** and *** indicate the 5% and 1% statistical significance levels, respectively.

3.4. Diagnostics & Stability Tests

Table 6 shows that several tests, including heteroskedasticity, LM, and Jarque-Bera tests were used to assess the quality of residuals from the selected ARDL model. The results showed that the model is free from autocorrelation and heteroscedasticity. Furthermore, they confirm the normal distribution of the residuals. Moreover, the model has a high adjusted R-squared value.

Finally, to investigate the parameter stability of the ARDL (1,2,0,1,0,2) model, this study used tests for cumulative sum and cumulative sum of squares to validate the long-run stability parameters of the variables (Pesaran & Pesaran, 1997). Both CUSUM and CUSUMSQ statistically fall within critical limits at 5% significance, as shown in Figures 2 and 3. As a result, the stability of the selected ARDL (1,2,0,1,0,2) model is confirmed; the estimated coefficients of the variables are stable throughout the study period.

Table 6. Residual diagnostics for ARDL (1,2,0,1,0,2) model.

Tests	**χ^2 (p-value)**
Adjusted R-squared	0.998
F-statistic	12.66***
Breusch-Pagan-Godfrey H test	1.376 (0.268)
Breusch-Godfrey LM test	1.113 (0.354)
Normality test (Jarque-Bera)	2.822 (0.244)

Notes: $\chi 2$ is the chi-squared, and the p-value is the probability value. LM: serial correlation Lagrange multiplier test; H: heteroskedasticity test. *** indicates the 1% significance level.

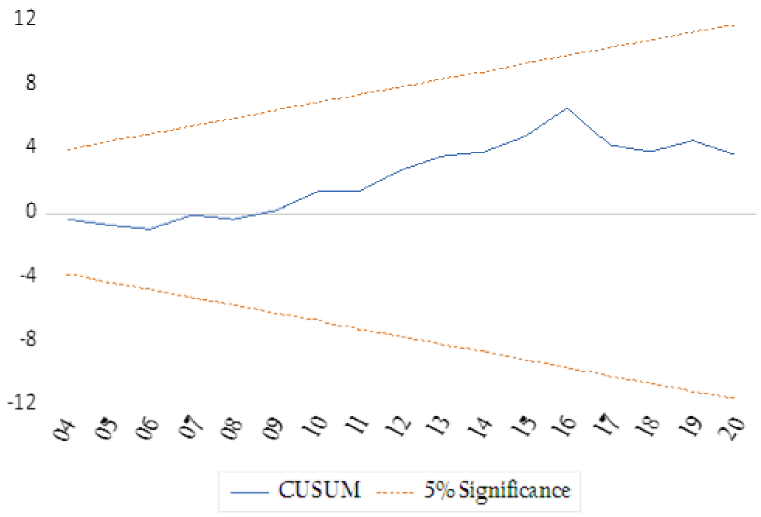

Figure 2. Plot of CUSUM test.

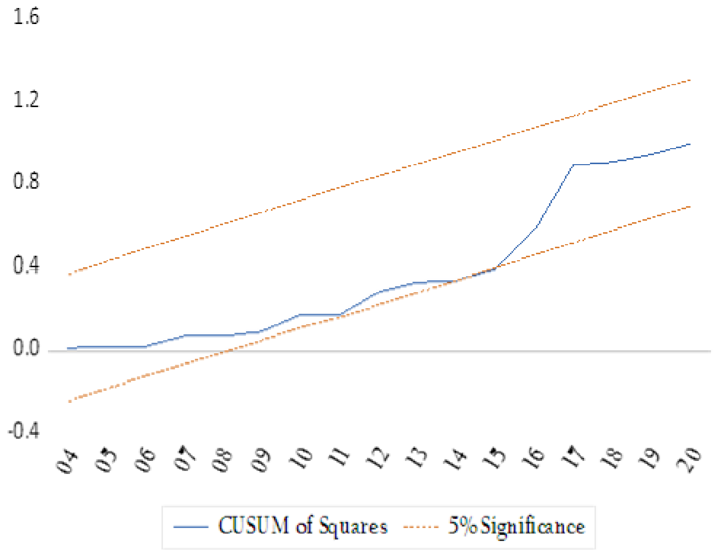

Figure 3. Plot of CUSUMSQ test.

4. DISCUSSION & CONCLUSION

This research has examined the effects of climate change factors and relevant economic factors on Egyptian AGDP from 1990 to 2020. Egypt was chosen as a case study because the agriculture sector remains the backbone of the Egyptian economy, representing approximately 71.3 % of GDP during the study period. Furthermore, it is considered one of the countries most susceptible to the potential effects of climate change. In this study, the ARDL model was used as the econometric method. The ARDL bounds test confirms the variables' long-run equilibrium. The long-run and short-run coefficients were then estimated using ARDL-ECM.

In the long run, CO_2 levels will rise, leading to higher temperatures, which will have a negative impact on Egypt's agriculture sector, particularly in arid and semiarid areas where rising temperatures cause soil evaporation, leading to increased salinity and land degradation. These findings agree with the majority of prior studies in other countries, such as Alam (2013), who demonstrated, using the ARDL model, that there is a negative relationship between economic growth and carbon dioxide emissions in India, while there is a positive relationship between economic growth and agricultural output. Furthermore, using the Johansen cointegration approach, Rahim and Puay (2017) discovered a long-run cointegration between Malaysia's GDP and its arable land, precipitation, and temperature. Furthermore, using the ARDL model, Rehman et al. (2019) confirmed that in Pakistan, there is a positive long-run relationship between energy consumption, water availability, cropped areas, fertilizer consumption, GDP per capita, and carbon dioxide emissions, using the ARDL model. Agricultural investment is expected to rise. Egypt intends to implement projects relating to vertical expansion and the development of plant varieties adapted to extreme climatic conditions, as well as modern irrigation projects relating to production requirements, according to the Ministry of Agriculture.

In the short run, CO_2 levels in the atmosphere have increased as a result of human activities including the use of fossil fuels, which has caused significant changes to the climate, including global warming, storms, floods, and rising sea levels. The rise in temperatures has resulted in a decrease in agricultural GDP. This result is consistent with Kilicaslan and Dumrul (2017), who found that rising temperatures have a negative impact on agricultural GDP in Turkey. According to the IPCC, CO_2 is the main cause of rising average global temperatures, which are expected to have risen by 3.5°C by 2100 (El-khalifa et al., 2020; Kim, 2012). This rise in temperatures has already resulted in a decrease in crop productivity, particularly in arid and semi-arid areas that suffer from a lack of water and fertility, resulting, in turn, in an increase in the size of the food gap to approximately 67.7% due to Egypt's rapid population growth. This is consistent with Onyeji and Fischer (1994), who predicted that rising CO_2 levels in the atmosphere would have a negative impact on agriculture in Egypt and that these negative effects would have a broader economic impact in certain scenarios. Also, El Raey and Book (2010) expected that global warming would cause water shortages in Egypt resulting in an increase in the severity and frequency of heat waves, as well as the severity and frequency of sand and dust storms. Furthermore, rising temperatures cause soil evaporation, which increases soil salinity; nearly 35% of Egypt's agricultural lands are salinized.

Recently, Egypt has prioritized land reclamation through horizontal expansion projects such as the New Delta project and other projects in North and Central Sinai. In combination with projects in agricultural manufacturing, packaging, export, export stations, and urban communities, this has resulted in an increase in agricultural investment. In consequence, Egypt's cultivated areas have increased by 3.44 million hectares in the short run.

Furthermore, food prices are expected to rise globally, including in Egypt, as a result of lower yields caused by climate change, and income is expected to fall. Moreover, it has been demonstrated that climate change has a negative impact on land degradation. This is supported by the findings of Abdel-Rahman et al. (2021) in Kafr El-Sheikh Governorate, Egypt, who identified four major deterioration risks: water-logging, soil compaction, salinization, and alkalization. Also, previous studies using the ARDL model have confirmed that emitted CO_2 has a positive effect on AGDP and that temperature decreases cause a decrease in agricultural GDP in China in both the long and the short run (Chandio et al., 2020). Furthermore, Akadiri et al. (2020) and Garidzirai (2020) pointed out using the ARDL model that energy use for consumption and production activities, as well as population growth, have positive impacts on emitted carbon dioxide and thus increase environmental degradation, whereas carbon taxes reduce carbon emissions. Meanwhile, Kim (2020) pointed out that in the long run, urbanization and economic growth contribute to an increase in greenhouse gas emissions, whereas nuclear energy and renewable energy contribute to a decrease in these emissions.

Climate change affects all sectors of development in Egypt, but especially water supplies and agricultural resources in arid to semi-arid environments. The Egyptian government is aware of these challenges, and they were incorporated into its Vision 2030. Confronting or adapting to climate change might take the form of proposing projects aimed at mitigating it. Furthermore, using environmentally friendly irrigation systems that produce fewer greenhouse gas emissions, such as using solar energy to power underground wells or water pumps, is one way to mitigate the effects of climate change.

Funding: This study received no specific financial support.
Competing Interests: The authors declare that they have no competing interests.
Authors' Contributions: All authors contributed equally to the conception and design of the study.

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