IMPACT OF CLIMATE CHANGE FACTORS ON MOROCCO'S AGRICULTURAL GDP

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ABSTRACT

Climate change has been identified as a major challenge facing the world in the 21st century. The fact that the economies of developing countries depend on agriculture makes the effects of climate change even more pronounced. In Morocco, the rate of growth is closely linked to the rate of agricultural production. Our study is related to the impact of climate change on the Moroccan agricultural sector. The analysis covers the period 1966 to 2021 in order to estimate the short and long term impacts of climate change on agricultural GDP. In order to study the possible effects of climate change on the agricultural sector, the relationship between temperature, rainfull, CO_2 emissions and agricultural GDP was estimated using the cointegration model ARDL (Autoregressive distributed lag). The empirical results show a positive and significant relationship between rainfall and agricultural GDP. However, the 1°C increase in temperature has a negative impact on agricultural GDP with a decrease of 2.07% in the short term and 1.26% in the long term. In addition, the impact of CO_2 emissions is estimated to be negative and statistically insignificant. This result may be due to the fact that carbon dioxide emissions in Morocco are low compared to industrialized countries. The findings confirm that climate change is negatively affecting Morocco's agricultural sector.

Keywords: Climate change; Impact; Agricultural GDP; ARDL; Rainfall; Temperature.

Résumé

Le changement climatique a été identifié comme l'un des défis les plus redoutables auxquels le monde est confronté au XXIe siècle. Le fait que les économies des pays en développement dépendent de l'agriculture rend les effets du changement climatique encore plus prononcés. Au Maroc, le taux de croissance est étroitement lié au taux de production agricole. Notre problématique s'inscrit autour de l'impact de changement climatique sur le secteur agricole Marocain. L'analyse couvre la période 1966 à 2021 afin d'estimer les impacts à court et à long terme de changement climatique sur le PIB agricole. Afin d'étudier les effets possibles de changement climatique sur le secteur agricole, la relation entre la température, les précipitations, les émissions de CO_2 et le PIB agricole a été estimé en utilisant le modèle de cointégration ARDL (Autorégressif à retards échelonnés). Les résultats empiriques montrent l'existence d'une relation positive et significative entre la pluviométrie et le PIB agricole. Cependant, l'augmentation de 1°C de la température impacte négativement le PIB agricole avec une diminution de 2.07% à court terme et de 1.26% à long terme. De plus, l'impact des émissions de CO_2 est estimé négatif et statistiquement non significatif. Ce résultat peut-être dû au fait que les émissions de dioxyde de carbone au Maroc sont faibles par rapport aux pays industrialisés. Les conclusions confirment que le changement climatique affecte négativement le secteur agricole marocain.

Mots clés : Changement climatique ; Impact ; PIB agricole ; ARDL ; Pluviométrie ; Température.

I. INTRODUCTION

Climate change is widely recognized as one of the major crises facing nations, given its direct link to the very survival of humanity. Its effects have a significant impact on all living things and ecosystems, resulting in natural disasters, health problems, water and food shortages, and complex interactions between living things and their environment (BAŞOĞLU and Al, 2013). Among the sectors most vulnerable to climate change, agriculture holds a prominent position due to its close dependence on weather conditions and events. The changing climate poses a severe threat to food security and agriculture, especially in many developing countries (Chandio, Ahsan, & Fang, 2020; Kilicaslan & Dumrul, 2017). Agriculture also plays a crucial role in sustaining rural communities by being a major source of income (Chandio et al., 2020). Additionally, the agricultural sector significantly contributes to GDP growth by providing raw materials, creating jobs in the industrial sector, and generating income that promotes economic development. Despite technological advancements, agriculture remains intrinsically linked to nature (H. Naci BAYRAÇ et Al, 2015).

As an economic activity, the changes in production caused by climate change are of great importance both at the national and international level, especially in terms of trade. Agriculture is positioned as both a contributor to climate change and a sector impacted by its effects. Agricultural activities such as tillage, fertilisation, pesticide spraying and food supply chain processes, as well as changes in the use of agricultural land, energy consumption and manure emissions from livestock contribute to carbon emissions (H. Naci BAYRAÇ and Al 2015). As per the findings of the Intergovernmental Panel on Climate Change (IPCC), the primary driver of global warming is carbon dioxide (CO_2), which is projected to cause an average global temperature increase of approximately 0.3°C per decade throughout the next century (El-khalifa, El-Sheikh, & Zahran, 2020; Kim, 2012). If no additional mitigation measures are implemented, the AR5 Climate Change report (2014) forecasts a significant 3.5°C rise in global average temperature by the year 2100. This rise in temperature has a direct impact on precipitation patterns, leading to alterations in the distribution of rainfall. A decline in precipitation levels can trigger water crises in the agricultural sector (Rahim & Puay, 2017). Consequently, climate change is already causing substantial economic losses worldwide due to an increased frequency of natural disasters like floods, storms, and droughts. The threat to food security is exacerbated by climate change, particularly due to the world's burgeoning population and the escalating demand for food (Rabbi & Tabassum, 2020; Rehman et al., 2019), contributing to a continuous surge in CO_2 emissions. Studies such as Deschênes and Al. (2007) highlight the growing consensus on the impact of human-induced greenhouse gas emissions on temperature and precipitation. These climate changes have the potential to impact the economic well-being of societies. In this context, since temperature and precipitation conditions play a crucial role in agricultural production, many experts believe that the agricultural sector will be particularly affected by the effects of climate change (Deschênes and Al., 2007).

The Moroccan agricultural sector has already experienced negative impacts of climate change, placing the country among the most sensitive to its potential effects. Sudden climatic variations, such as extremely cold winters, long and extremely hot summers, as well as off-season rains, have been observed. The main objectives of this research are to study the effects of climate change factors on Morocco's agricultural GDP from 1966 to 2021, in order to help Moroccan decision-makers anticipate and prepare for the long-term consequences on the agricultural sector. It also aims to test the hypothesis that climate change will have a long-term impact on Moroccan agriculture. In this study, an autoregressive distributed lag model (ARDL) is used to obtain precise parameters and examine the long-term influence of climate change on the Moroccan agricultural sector. It should be noted that the existing literature on this subject is limited or non-existent, which underlines the importance of this research to better understand the short- and long-term impacts of climate factors such as temperature, CO_2 and precipitation on Morocco's agricultural GDP. The results of this study should help identify the most important factors affecting the agricultural sectors of developing countries, thus playing a key role in mitigating the adverse effects of global climate change.

The next section of the study focused on a literature review, exploring previous work related to the topic. Subsequently, the stylized facts specific to Morocco regarding the impacts of climate change were stated. The data set used in the study and the econometric methodology used were then presented. In order to examine the potential effects of climate change on the agricultural sector in Morocco, an analysis was carried out over the period from 1966 to 2021 using the ARDL model. This analysis sought to establish the relationship between agricultural GDP and various variables such as CO_2 emissions, temperature and precipitation. The results obtained in this study showed that variations in rainfall have a positive and significant impact on agricultural GDP in Morocco. In contrast, changes in CO_2 emissions have been associated with a negative impact on agricultural GDP. In addition, it was concluded that changes in temperature have a negative effect on the agricultural sector. These results highlight the importance of climate factors in the context of agriculture in Morocco, highlighting the challenges posed by climate change on the economic performance of the agricultural sector.

These findings could be useful for policy makers to better anticipate and adapt to the impacts of climate change on agriculture in the country.

II. LITERATURE REVIEW

In the empirical literature, different approaches have been used to assess the link between climate and agriculture (Mendelsohn & Dinar, 2009): **the Ricardian approach** (Mendelsohn et al., 1994) based on land values, **net income approaches** (Deschênes and Greenstone, 2007)**,** **crop simulation models** (Rosenzweig et al., 2014), and **agricultural production or yield functions (**Lobell et al., 2011; Chen et al., 2016),

1. Ricardian approach

The hedonic or land value approach attempts to directly measure the impact of climate on land value. According to Deschênes, O and Greenstone, M (2007), the advantage of this approach is that, if land markets work properly, prices will reflect the present value of land rents in an infinite future. In principle, this approach takes into account all aspects of farmers adaptation. However, its validity depends on consistent estimates of climate impacts on land values. At least since the classic articles of Irving Hoch (1958, 1962) and Yair Mundlak (1961), it was recognized that non-measurable characteristics such as soil quality and the value of conversion options to new uses are important determinants of production and land. Therefore Deschênes, O; Greenstone, M, also found that the hedonic approach was unreliable as it produces estimates that are extremely sensitive to seemingly minor choices regarding control variables, the sample and the weighting (Deschênes and Al, 2007) . In 1994 Robert M, William D. N and Daigee S, measured the economic impact of climate on land prices. These authors used cross-sectional data on climate, farmland prices, and other economic and geophysical data for nearly 3,000 counties in the United States.

The results show that higher temperatures in all seasons except autumn reduce average agricultural values, while more precipitation outside autumn increases agricultural values. Applying the model to a global warming scenario shows an estimated impact of global warming on US agriculture significantly lower than the traditional production function approach. On the other hand, Deschênes, O and Greenstone, M (2007) found that the estimated impact of climate change on the value of U.S. farmland ranged from $200 billion (in 2002 dollars) to $320 billion (or 18% to 29%). This variation in predictive impact is caused by seemingly insignificant decisions about appropriate control variables, samples and weights. Despite its theoretical appeal, Deschênes, O and Greenstone, M (2007) concluded that the hedonic farm value approach may not be reliable in this context.

2. The net income approach

Instead of relying on empirical measurements of crop yields over time, an alternative approach to assess the impact of climate change on agriculture is by examining changes in net farm incomes. This can be achieved through panel data analysis, as demonstrated by Deschenes and Greenstone (2007). By utilizing fixed effects in the analysis, this method accounts for inherent differences between counties, including their specific climates, as well as other factors that may be challenging to quantify. The focus of this approach is on intertemporal variations between counties, which capture annual fluctuations in weather conditions. As a result, it becomes a suitable method to measure short-term responses to abrupt weather changes. However, it's worth noting that this approach shares the same limitations as yield studies, as it does not directly account for adaptation strategies implemented by farmers to cope with changing climate conditions.

In 2007, Deschênes, O and Greenstone, M measured the economic impact of climate change on the US agricultural sector. The analysis estimates the impact of annual stochastic variations in temperature and precipitation on agricultural benefits. Using the Hadley 2 model for long-term climate change projections, the preferred estimate indicates that climate change would increase the annual returns of the agricultural sector by $1.3 billion (in 2002 dollars), or 4%. In addition, the analysis shows that projected increases in temperature and precipitation will have little effect on yields of the most important crops (maize, cereals and soybeans), suggesting that the low impact on profits was not due to short-term price increases.

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3. crop simulation models

One of the widely used and popular methods for assessing the impact of climate change on agriculture is through the application of crop simulation models. These models incorporate functions that capture the intricate interactions between crop growth and various factors, including climate, soil conditions, and management practices. They are developed based on a comprehensive understanding of agronomic science and can be effectively linked to hydrological conditions (Mendelsohn R and Dinar, A ,2009). Additionally, crop simulation models can consider the effects of carbon dioxide fertilization, making them valuable tools for studying the impacts of climate change on crops. They are also calibrated specifically for selected locations, which enhances their accuracy in localized assessments. Despite their advantages, crop simulation models do have notable limitations. One of the most significant concerns is their inability to account for farmer behavior and management practices. These models assume that farmers practices remain fixed or exogenous, without considering potential changes in response to climate variations (Mendelsohn R and Dinar, A ,2009). This lack of adaptation in the models means that they may not accurately predict how farmers will adjust their practices in the face of changing climatic conditions. To address this limitation, researchers often introduce adaptation exogenously in crop simulation studies.

In 2014, Rosenzweig and Al conducted a comprehensive study using seven global grid crop models to simulate global crop yields under changing climate conditions. Their research examined climate responses across various crops, latitudes, time periods, regional temperatures, and atmospheric carbon dioxide concentrations. The consistent results from multiple models indicated significant negative effects of climate change, particularly in regions with higher warming levels and lower latitudes where many developing countries are situated (Rosenzweig and Al, 2014). In conclusion, while crop simulation models offer valuable insights into the potential impacts of climate change on agriculture, their inability to fully incorporate farmer adaptation remains a key limitation. Nevertheless, when carefully utilized and complemented with other approaches, such as socio-economic assessments, crop simulation models contribute substantially to understanding the complex dynamics of climate change effects on global crop production.

4. Agricultural production or yield function

According to Jones et al, the agricultural production function has been used by a large number of authors to analyse the link between climate change and agricultural production at different scales (countries, regions, etc.). Move from standard mean temperature and precipitation measurements to other measures capturing solar radiation, droughts and floods, using different methodologies and climate indicators (Jones et al, 2017). In fact, some empirical research has focused on the analysis of the effects of climate change on agriculture. In 2009, You and Al analyzed the effects of monthly temperature and precipitation, solar radiation, chemical fertilizers, farmland, irrigation, seed and wheat yield machines in 22 major wheat-producing provinces in China. Results showed that a 1°C increase in temperature during the wheat growing season would reduce wheat yield by about 3-10%. Similarly, in 2016, Kahsay and Hansen investigated the impact of climate and other physical variables. (i.e., labour, land, machinery, livestock, fertilizers and irrigation) on agricultural production. The analysis included nine East African countries from 1980 to 2006, using the panel data model analysis to confirm the significant effects of mean growing season temperature and precipitation and their variances. Similarly, Xu and Al. (2019) found that seasonal precipitation and its duration had a significant positive effect on agricultural production in 751 counties of the Yangtze River Basin in China, while the average temperature during the growing season had a significant negative impact on agricultural production.

In 2010, Brown and Al analyzed the impact of precipitation and temperature on agricultural GDP growth. The analysis covered 133 countries in the world between 1961 and 2003. The results of the fixed-effect panel model show that an increase in temperature reduces agricultural GDP, while a decrease in precipitation negatively impacts agricultural GDP. On the other hand, the impact of climate change has been analysed using time series models. Indeed, Başoğlu, A. ve Telatar, OM (2013) examines the impact of climate change on Turkish agriculture. For this purpose, the model was estimated using time series analysis for the period 1973-2011. The results show that for each unit of increase in annual precipitation change, agriculture's share of GDP increases by 0.06%. Thus, for each unit of increase in annual temperature change, the share of agriculture in GDP decreases by 0.12%. Similarly in 2016 Bayraç, H.N and Doğan, E. studied the impact of climate change on the Turkish agricultural sector during the period 1980-2013. In order to study the possible impact of climate change on the agricultural sector, an ARDL Autoregressive Distributed Lag model was used to estimate the relationship between agricultural productivity, CO2 emissions, temperature, precipitation and GDP. Empirical results show that there is a significant positive correlation between agricultural productivity, precipitation and agricultural GDP. However, the impact of CO_2 emissions on agricultural GDP is estimated to be negative and statistically significant. The results of this study confirm that climate change has a negative impact on the agricultural sector. According to El-Khalifa and

Al. (2022) Climate change will have long-term impacts on Egypt's agricultural sector. In the long term, carbon dioxide is the main cause of rising temperatures in Egypt. In the short term, climate change is happening because atmospheric carbon dioxide levels are rising, causing global warming, storms, floods and rising sea levels. As a result, rising temperatures reduce agricultural GDP.

III. STYLIZED FACTS

Morocco exhibits significant climatic variation from the north to the south of the country, with strong influence from the Atlantic Ocean to the west, the Mediterranean Sea to the north and the Sahara desert to the south and south-east (World Bank (2018). According to the United Nations Development Programme, the observed trends have revealed an increasing irregularity in rainfall and an overall decrease in rainfall (UNDP, 2012). Similarly, the World Bank has found that arid and semi-arid regions in the south and south-east of the country generally experience high temperatures (World Bank, 2018). Indeed, in recent decades, the Moroccan climate has already recorded an increase in temperatures and a notable decrease and a great variability in precipitation. The World Bank highlighted Morocco's high vulnerability to climate variability and change. Forecasts indicate a worrying increase in the frequency and intensity of droughts in the country, which will have significant consequences for the agricultural sector, affecting both the livelihoods of rural populations and the national economy as a whole (World Bank, 2018). However, the agricultural sector is central to the Moroccan economy, contributing nearly 13% to GDP. This contribution is considered essential because economic growth in Morocco is closely linked to the level of agricultural production (Moroccan Ministry of Agriculture, 2018). Despite the increased resilience of the country's economy as a whole, agriculture remains vulnerable due to its dependence on precipitation and climate variability, particularly the occurrence of droughts.

Morocco is among the countries exposed to the risks of the potential impacts of global warming. In particular, it could suffer the adverse consequences of declining water resources, forest fires, drought and desertification. As greenhouse gas concentrations in the atmosphere continue to increase, climate change that could occur in the coming years would exacerbate water resource problems in arid and semi-arid areas. The main cause of global warming is attributed to the increase in the concentration of greenhouse gases in the atmosphere, mainly due to economic activities. In 2021, the United Nations Environment Programme announced that Morocco's greenhouse gas emissions amounted to 101.2 million tonnes in 2018, compared to 13,739.8

million tonnes for China and 6,297.6 million tonnes for the United States. Carbon dioxide (CO2) is one of the main greenhouse gases contributing to climate change. Morocco’s contribution to global emissions remains low compared to the adverse effects of climate change. In this regard, Morocco is an example of the paradox of climate change. In this context, our study aims to study the impact of climate change factors on agricultural GDP.

IV. RESEARCH METHODOLOGY AND DATA SOURCES

1) Research methodology

In this research, we employ the Autoregressive Distributed Lag (ARDL) model, initially introduced by Pesaran and Shin (1999) and later expanded upon by Pesaran, Shin, and Smith (2001), to assess the impacts of climate change on Morocco's agricultural sector. The ARDL model is implemented using EViews 12 software and offers several advantages, making it suitable for small datasets and cases where variables are integrated at level I (0) or first difference I (1), but not I (2) (Sarkodie & Owusu, 2020).

The primary focus of the ARDL model is to investigate the long-term cointegration relationship between agricultural GDP and climate-related variables, namely temperature, rainfall, and CO_2 emissions. This relationship is expressed through Equation 1, allowing us to explore the dynamic interplay between these factors and their effects on the agricultural sector over time.

$$\Delta \boldsymbol{AGDP_t} = \propto_0 + \sum_{k=1}^{p} \propto_{1k} \Delta \boldsymbol{AGDP_{t-k}} + \sum_{k=0}^{p} \propto_{2k} \Delta \boldsymbol{TEMP_{t-k}} + \sum_{k=0}^{p} \propto_{3k} \Delta \boldsymbol{RF_{t-k}} + \sum_{k=0}^{p} \propto_{4k} \Delta \boldsymbol{CO_{2t-k}} + \boldsymbol{\beta_1 AGDP_{t-1}} + \boldsymbol{\beta_2 TEMP_{t-1}} + \boldsymbol{\beta_3 RF_{t-1}} + \boldsymbol{\beta_4 CO_{2t-1}} + \boldsymbol{\varepsilon_t} \tag{1}$$

Where $\propto_0$ represents the intercept, $\propto_1, \propto_2, \propto_3$ ***and*** $\propto_4$ represent the short-run relationships, $\boldsymbol{\beta_1}, \boldsymbol{\beta_2}, \boldsymbol{\beta_3}$ and $\boldsymbol{\beta_4}$ represent the long-run relationships, **ρ** indicates the lag order, Δ denotes the first difference operator, **t-1** represents time lag, and $\boldsymbol{\varepsilon_t}$ indicates the error term.

The ARDL test is a valuable tool utilized to assess the presence of a long-term relationship between agricultural GDP (AGDP) and the long-term variables, namely temperature, rainfall, and CO_2 emissions. In this context, the null hypothesis (H0) postulates that there is no cointegration between AGDP and the long-term variables, while the alternative hypothesis (H1) suggests the presence of cointegration between them. The comparison between the calculated F statistic and the critical values corresponding to the upper and lower limits, namely I (1) and I (0), is conducted following the approach of Narayan (2005) and Pesaran et al. (2001). If the calculated F (or t) statistic exceeds the critical values, H0 is rejected, indicating the existence of a long-term cointegration relationship between AGDP and the long-term variables. Conversely, if the calculated F (or t) statistic does not exceed the critical values, H1 is rejected, suggesting that there is no cointegration between the variables. In cases where the calculated F (or t) statistic falls between the lower and upper bounds, the co-integration between the variables is considered inconclusive.

Once the bound test confirms the presence of a long-term relationship between the variables, the next step involves estimating the short-run coefficients and constructing the Error Correction Model (ECM) in the ARDL model. This is achieved through the following equation:

$$\Delta AGDP = \propto_0 + \sum_{k=1}^{p} \propto_{1k} \Delta AGDP_{t-k} + \sum_{k=0}^{p} \propto_{2k} \Delta TEMP_{t-k} + \sum_{k=0}^{p} \propto_{3k} \Delta RF_{t-k} + \sum_{k=0}^{p} \propto_{4k} \Delta CO_{2t-k} + \delta ECM_{t-1} + \varepsilon_t \tag{2}$$

Subsequently, the study assesses the stability of the ARDL model using cumulative sum (CUSUM) and cumulative sum of squares of residuals (CUSUMSQ) statistics. By comparing these values to critical limits defined at a significance level of 5%, the researchers can determine whether the model exhibits stability (Borensztein, De Gregorio, and Lee, 1998; Granger, 1988). Achieving stability ensures the reliability of the model's results and enhances the confidence in its findings. Following the estimation of the ARDL model, several diagnostic tests are conducted to validate the accuracy of the coefficient estimates. The Breusch-Godfrey serial correlation test (LM test) is employed to identify the presence of autocorrelation (Godfrey, 1978). The Jarque-Bera statistics-based normality test is utilized to assess the normality of the model's residuals (Jarque & Bera, 1980). To detect heteroscedasticity, the Breusch-Pagan-Godfrey test is applied (Engle, 1982).

By conducting these diagnostic tests, the study ensures the robustness of the ARDL model and addresses potential issues of stability, autocorrelation, non-normality, and heteroscedasticity. Validating the model in this manner enhances the credibility of the results and strengthens the overall reliability of the study's findings.

2) Data sources

The time series data used in the study are from the World Bank database and cover the period 1966-2021. The variables used in the model are presented in the table below:

Table 1: Study Variables

Variable	Description	Unit of measurement
AGDP	Gross Domestic Product Agriculture	%
TEMP	Temperature	°C
RF	Precipitation	mm
CO_2	CO2 emissions	Kilotons

V. RESULTS

1) Descriptive Statistic

The basic statistics of the variables used in the study are presented in the table and figure below. Table 2 shows the descriptive statistics of the climate change factors, temperature, rainfall and CO_2 emissions that have an impact on agricultural gross domestic product (AGDP) in morocco from 1966 to 2021. The table shows the mean, standard deviation, highest and lowest values in the series and the year in which the values were obtained. Figure 1 shows the time series of the study variables. They were not stable during the study period, as shown in Figure 1.

Table 2: Descriptive statistics of variables during 1966-2021.

Variable	Observation	Mean	Standard deviation	Maximum	Minimum

AGDP	57	15.018	3.653	23.445 (1965)	10.321 (2016)
TEMP	57	20.736	0.581	21.770 (2010,2017)	19.380 (1972)
RF	57	365.08	80.61	608.46 (1996)	219.20 (1981)
CO_2	55	29954.02	19128.58	71480.00 (2019)	4261.054 (1965)

Source: produced by the authors

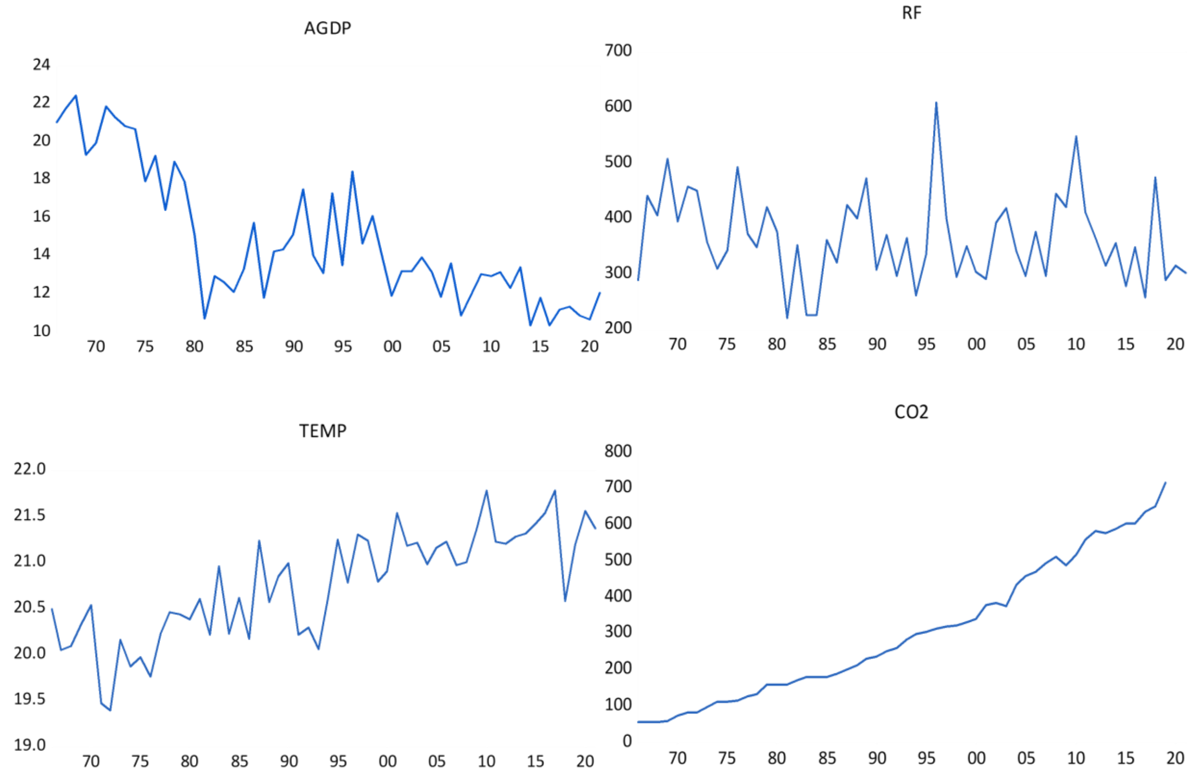

Figure 1. EViews 12 – outputs of variables time series plots.

2) Stationarity Analysis (Unit Root Test)

Before making estimates, it is important to verify the stationarity of the variables and to ensure that the errors meet the conventional regression assumptions, that is, that they have a zero mean and finite variance. Granger and Newbold (1974) noted that non-stationary variables can lead to misleading regression results. Thus, in this study, the unit root tests of Dickey Fuller Augmented (ADF) (1981) and Phillips-Perron (PP) (1988) are used to test the stationarity of variables. The results of these tests are presented in Table 3.

Table 3: Results of unit root tests.

Variables	ADF	1%	5%	10%	Proba	PP	1%	5%	10%	Proba
AGDP	-12.95	-4.13	-3.49	-3.17	0.000	-15.28	-4.13	-3.49	-3.17	0.000
TEMP	-6.43	-4.13	-3.49	-3.17	0.000	-6.43	-4.13	-3.49	-3.17	0.000
RF	-6.43	-4.13	-3.49	-3.17	0.000	-6.63	-4.13	-3.49	-3.17	0.000
CO_2	-6.52	-4.14	-3.49	-3.17	0.000	-7.884	-4.14	-3.49	-3.17	0.000

Source: produced by the authors

According to the results of the ADF and PP tests, the rainfall (RF) and temperature (TEMP) variables are stationary at level I(0). On the other hand, the variables of agricultural GDP (AGDP) and CO_2 emissions (CO_2) are stationary after a primary difference, that is to say they are I(1). This means that with a combination of I(0) and I(1) at the 1% and 5% significance threshold, all variables are stationary and the ARDL model can be used to show a strong long-term relationship between the variables in this study.

3) ARDL Model and Bounds Tests

Since the series have different degrees of stationarity according to unit root tests, it is possible to estimate short and long term relationships using bounds tests. This method allows cointegration to be applied to series with different degrees of cointegration. The optimal number of lag in the model is determined using the Akaike Information Criterion (AIC), with a maximum of 4 lag. The results of the cointegration test at the Pesaran terminals are presented in the table 4.

Table 4: ARDL Bounds Tests

	Value	**Signification**	Bound **I(0)**	Bound **I(1)**
F Statistic	8.443481	10%	2.37	3.2
k	3	5%	2.79	3.67
		2.5%	3.15	4.08
		1%	3.65	4.66

Source: produced by the authors

The results in Table 4 show that the calculated value of the F-statistic is 8.443481 and the t-statistic value is 3. The results of the bounds test using the selected ARDL (1, 2, 3, 0) 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 AGDP is the dependent variable and CO_2, TEMP, and RF are independent variables.

Based on the results obtained from the table 4 estimates, Pesaran et al. (2001) determined that the statistical value of F was greater than the upper critical value. These results indicate the existence of a cointegration relationship between the variables, and the H0 hypothesis, which suggests the absence of cointegration between the variables, is rejected.

The results of estimating the short- and long-term relationship between climate change and agricultural GDP are presented in Tables 5 and 6.

Table 5: Short-term error correction model results

Variable	Coefficient	T Statistic	Probability
D(TEMP(-1))	2.070674	3.812889	0.0005
D(RF(-1))	-0.010457	-3.262474	0.0022
D(RF(-2))	-0.007297	-2.928824	0.0055
ECM(-1)*	-0.835772	-6.807068	0.0000

Source: produced by the authors under Eviews

According to the results in Table 5, the error correction term ECM(-1) in the error correction model is significant at the 1% threshold and displays a negative value. This observation suggests that the differences between the variables considered are corrected over the period considered. The negative sign indicates a converging process of correcting deviations towards long-term equilibrium in the model. Based on the estimation results in Table 5, the rainfall variable is statistically significant and positive in the short term. This finding indicates that the increase in the amount of rainfall in Morocco has a positive effect on agricultural GDP. On the other hand, the coefficient of the temperature variable is also significant in the short term and shows a negative value. These results imply that an increase of one degree Celsius in temperature leads to a decrease of 2.07 units of agricultural GDP. It should be noted that CO_2 emissions do not have a significant impact on agricultural GDP in the short term, which can be attributed to Morocco's low levels of CO_2 emissions. Despite the positive effect of rainfall (0.01) on agricultural GDP, the negative effects of climate change, resulting from the environmental problems associated with rising temperatures, are being felt in the agricultural sector.

Table 6: Long-Term ARDL Model Results

Variable	Coefficient	Standard deviation	T Statistic	Probability
TEMP	-1.264443	0.635988	-1.988155	0.0535
RF	0.009679	0.002940	3.292454	0.0021
CO_2	-0.001230	0.002594	-0.474095	0.6379

Source: produced by the authors under Eviews

Based on the results presented in Table 6, a 1 mm increase in rainfall leads to a 0.0096 unit increase in agricultural GDP over the long term. In addition, the estimation results indicate that temperature has a significant negative effect on agricultural GDP, with a coefficient of -1.264443. CO_2 emissions also have a negative but not significant effect on agricultural GDP, probably due to low levels of CO_2 emissions in Morocco. In short, the results show that precipitation has a positive impact on agricultural GDP, while temperature and CO_2 emissions have a negative impact. Despite the positive effect of precipitation on agricultural GDP, it is important to note that the overall impact of climate change on agricultural GDP remains negative.

4) Diagnostics and stability tests

Table 7 shows that several tests, including heteroscedasticity tests, Breusch-Godfrey LM and Jarque-Bera, were used to assess the quality of the residues of the selected ARDL model. According to the results of the analyses, the coefficient of determination R^2 reveals that temperature and precipitation explain approximately 59% of the observed variation in agricultural GDP. In other words, nearly 59% of the variability in agricultural GDP can be attributed to changes in temperature and precipitation. The results of the Jarque-Bera test indicate that the residues follow a normal distribution. In addition, the model does not have autocorrelation, as confirmed by the Breusch-Godfrey LM test (0.68). The Breusch Pagan Godfrey test also confirms the absence of heteroscedasticity (9.99). Finally, to study the stability of the ARDL model parameters (1, 2, 3, 0), this study used cumulative sum and cumulative sum squares tests to validate the long-term stability of the variable parameters (Pesaran & Pesaran, 1997). CUSUM and CUSUMSQ tests are statistically within critical limits of 5% significance, as shown in Figures 2 and 3. Therefore, the stability of the selected ARDL model (1, 2, 3, 0) is confirmed; the estimated coefficients of the variables are stable throughout the study period.

Table 7 : Residual diagnostics for ARDL (1, 2, 3, 0) model

Jarque-Bera	**1.378481 (0.91)**	**R^2**	**0.59**
Breusch Godfrey	0.688429 (0.64)	Adjusted R^2	0.54
Breusch Pagan Godfrey	9.990217 (0.35)	F Statistic	19.621 (0.00)

Source: produced by the authors

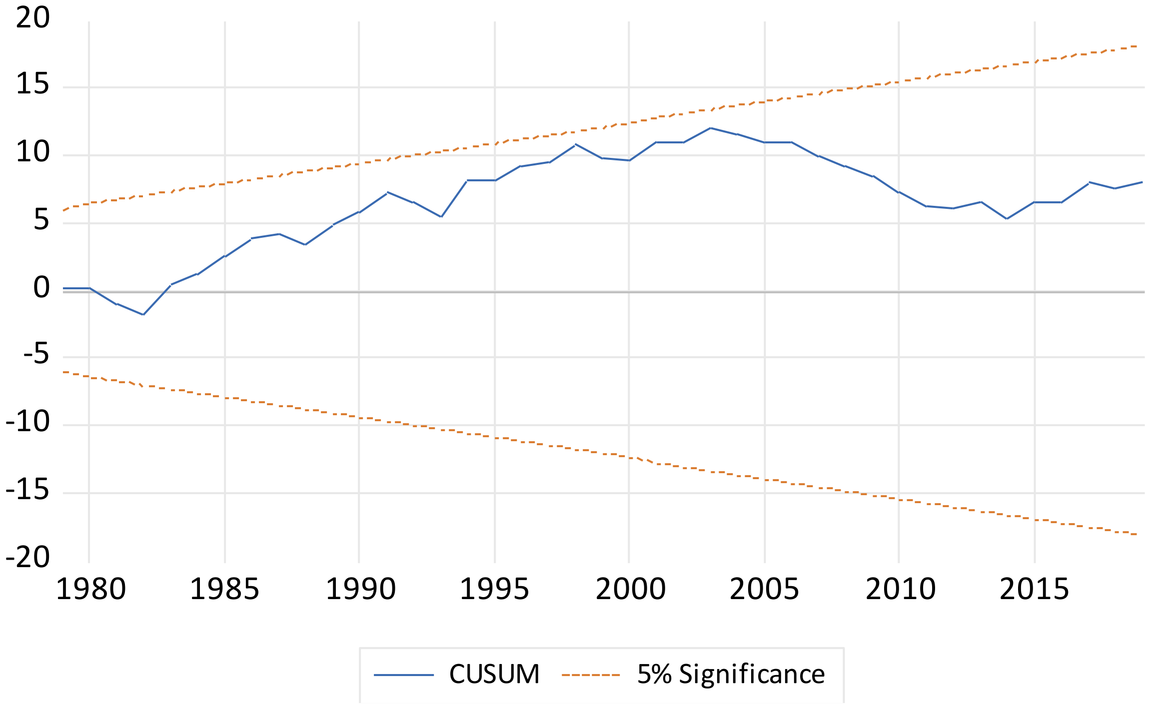

Figure 2 : Plot of CUSUM test

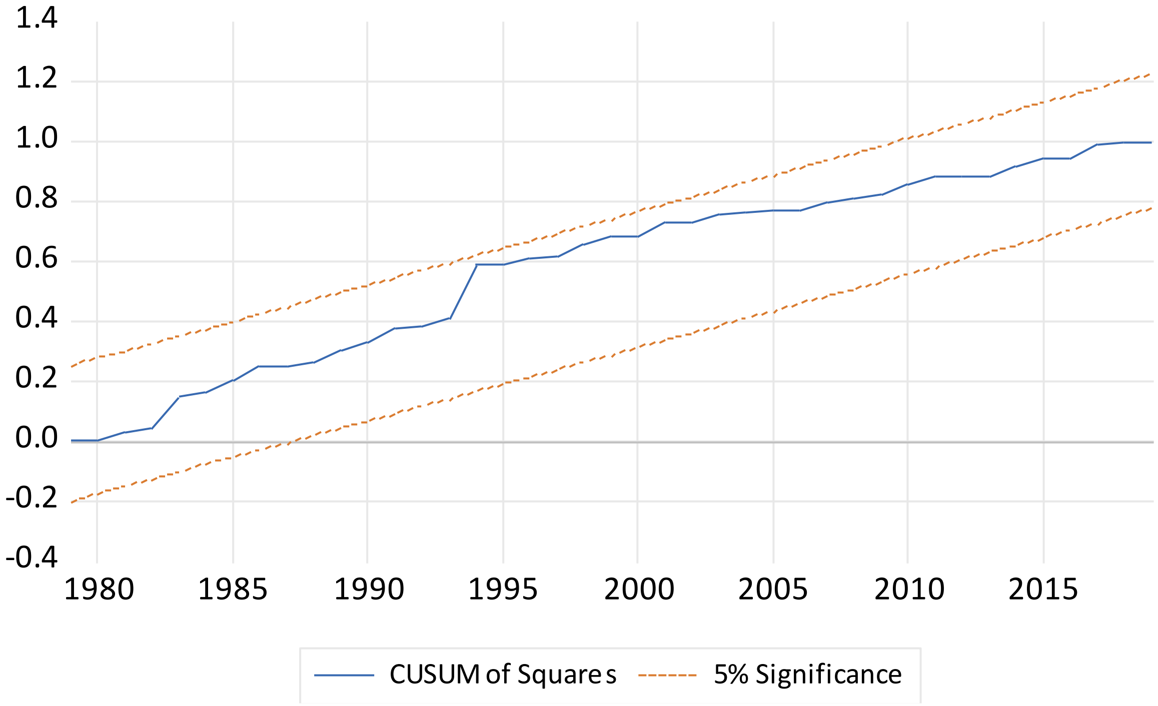

Figure 3. Plot of CUSUMSQ test.

VI. DISCUSSION & CONCLUSION

Changes in the volume of agricultural production are closely linked to all segments involved in the process, from production to consumption in agriculture, from farmers income to national income, from agriculture-based industry to industry using agricultural waste products (BAYRAÇ and Al, 2015). Due to agricultural activities such as land misuse and unconscious and excessive fertilisation, greenhouse gas emissions from carbon-producing soils are increasing. Today, because it is not possible to fully offset the effects of global greenhouse gas emissions, there is a greater emphasis on reducing the effects of climate change and adapting policies. In the 4th assessment report of the Intergovernmental Panel on Climate Change (IPCC), it is indicated that adaptation studies are of great importance in terms of managing the effects of climate change. This situation states that in order to take timely and more effective climate change adaptation actions, harmony and coordination between sectors and jurisdictions as part of a global strategic approach, are compulsory. Morocco's agricultural sector, which accounts for 13% of national income, plays a key role in the country's economy. Morocco's economic growth is closely linked to the rate of agricultural production. This sector is also of great economic and social importance, with a share of about 38% in total employment at the national level and about 74% in rural areas (Moroccan Ministry of Agriculture, 2018). Over the period 2008-2018, the volume of agricultural exports doubled from MAD 15.2 billion to MAD 36.3 billion. However, the effects of global warming are felt in Morocco in various forms and dimensions. These climate changes cause disturbances in agricultural activities, affecting the natural habitats of animals and plants, and causing significant problems in terms of the availability of water resources.

Morocco is committed to implementing various policies and strategies to address environmental challenges and foster sustainable development. Among these initiatives is the National Sustainable Development Strategy (NSSD), which pursues several objectives, including the reduction of greenhouse gas (GHG) emissions, increasing the share of renewable energy in the energy mix and strengthening the country's resilience to the impacts of climate change. Morocco has also implemented the National Water Plan (NWP) to better manage and preserve its water resources, which are facing increasing pressures due to climate change. To address the lack of water supply, the country is also exploring the use of other unconventional resources such as the desalination of seawater and the reuse of wastewater, as observed in the Souss Massa region (EL ISSAOUI, K. and BENKACHCHACH, K. 2021). In addition, the African Agricultural Adaptation Initiative is also an area where Morocco is actively involved in helping to promote sustainable agricultural practices, efficient irrigation and integrated management of natural resources to adapt to the impacts of climate change in the agricultural sector. These policies and strategies reflect Morocco’s strong commitment to preserving the environment, fighting climate change and promoting sustainable development to ensure a more resilient future for the country.

This study examines the effects of climate change on the agricultural sector in Morocco using annual data covering the period 1966-2021. The relationship between agricultural GDP and CO_2 emissions, temperature and precipitation was assessed using the AutoRegressive Distributed Lag (ARDL) model. The tests carried out confirmed the existence of a cointegration relationship. In addition, the error correction model based on the ARDL approach showed that the error correction term is negative and significant, and that the compliance rate is also high. The results indicate that changes in precipitation have a positive and significant effect on agricultural GDP. However, changes in CO_2 emissions have a negative but not significant effect on agricultural GDP, probably due to low levels of CO_2 emissions in Morocco. In addition, changes in temperature have been found to have a negative effect on the agricultural sector, reducing agricultural yield. In addition, the negative effect of temperature changes on the agricultural sector appears to be greater than the positive effect of precipitation changes, which leads to the conclusion that the overall effect of climate change on the agricultural sector is negative. These findings agree with the majority of prior studies in other countries, such as Bayraç, H.N and Doğan, E (2016), who demonstrated, using the ARDL model, that there is a positive relationship agricultural productivity, precipitation and agricultural GDP in Turkey, while there is a negative relationship between CO2 emissions on agricultural GDP. Furthermore El-Khalifa et al. (2022) discovered Climate change will have long-term impacts on Egypt’s agricultural sector. In the long term, carbon dioxide is the main cause of rising temperatures in Egypt. In the short term, climate change is happening because atmospheric carbon dioxide levels are rising, causing global warming, storms, floods and rising sea levels. As a result, rising temperatures reduce agricultural GDP.

To mitigate the adverse impacts of climate change on Morocco's agricultural sector, it is crucial to implement adaptation policies and strategies aimed at combating climate change and securing the nation's food security, with a particular focus on rainfed agriculture. Moreover, supporting the cultivation of agricultural products that are well-suited to withstand increasing temperatures in Morocco and raising awareness among farmers regarding climate change adaptation are essential steps to be taken. By adopting these measures, Morocco can effectively address the challenges posed by climate change and safeguard its agricultural productivity and food sustainability.

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