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Article

The impact of climate change on agriculture and economic growth in Cameroon

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Abstract: The agricultural sector is both one of the key sectors of the Cameroonian economy and the one most influenced by the climate. As indicated in the fifth report of the Intergovernmental Panel on Climate Change, the increase in the concentration of greenhouse gases in the atmosphere, the rise in temperature, changes in rainfall patterns, changes in cloud cover, etc., will continue to change. But how does climate change affect agricultural activities and influence economic growth in Cameroon? The aim of this article is to analyze the impact of climate change on agricultural production and on economic growth in Cameroon over the period 1990–2020. To achieve this objective, a stochastic production function model developed by Just and Pope was used. We also used CO_2 emissions as a proxy for climate change. The results obtained clearly show that the increase in CO_2 emissions has a negative impact on agricultural production and on economic growth.

Keywords: climate change; agriculture; economic growth; Cameroon

1. Introduction

The Intergovernmental Panel on Climate Change (IPCC)'s findings are leading us to fear the worst for humanity if nothing serious or effective is done to curb climate change (CC). The IPCC predicts that by 2100 the average global temperature will have risen by between 1.8 °C and 4 °C, and in the worst-case scenario by between 1.8 °C and 6.4 °C. The economic impact of CC has been estimated in particular by Stern [1]. For him, without strong and rapid action in the present (now), the economic development of humanity would generate risks of major disruptions in this century and the next on a scale comparable to those associated with the great wars and the economic depression of the first half of the 20th century. In other words, on a constant annual basis, climate damage[1] could account for between 5% and 20% of annual gross world product (GWP) today and for a very long time to come.

All these different predictions are worrying political leaders and human communities. Especially as these predictions are very negative for certain socio-economic sectors, including agriculture.

Throughout the world and in Cameroon, agriculture is still one of the sectors driving economic growth and people's well-being. It provides a livelihood for more than 3 billion of the world's seven billion people [2]. Developing countries base a large part of their economies on agriculture, i.e., 15%–20% of Gross Domestic Product (GDP). In addition, the agricultural sector employs around 26.75% to 60% (or 2.5 billion people) of the working population [3].

The relationship between climate change and agriculture continues to interest the scientific community [4–9]. The conclusions of theoretical and/or empirical analyses are almost unanimous: Despite its multifunctionality and its contribution to combating CC, the agricultural sector suffers enormously from the negative impacts of CC [6,10,11]. Indeed, the dual relationship between agriculture and the climate and the very high dependence of agriculture on climatic conditions make the agricultural sector very vulnerable to the risks caused by climate change. These risks exacerbate stress factors, having a direct impact on livelihoods, reducing crop yields or destroying the environment through water, air and soil pollution [12,13]. In return, local populations themselves remain heavily dependent on agricultural products. Farmers in Cameroon, for example, are increasingly demanding more land for their activities, sometimes using ecosystems that have already been degraded and weakened [5]. In addition, the demands of economic growth and well-being place these farmers in highly vulnerable situations.

Much remains to be said, however, about agriculture's great sensitivity to climate fluctuations, about the concerns that arise from this great sensitivity and/or about the ripple effects of CC on economic growth via agriculture [14–16]. It is therefore not surprising to ask how climate change is affecting agricultural activities and influencing economic growth in Cameroon?

The aim of this article is to analyze the impact of climate change on agricultural production and on economic growth in Cameroon over the period 1990–2020. To achieve this objective, a stochastic production function model of Just and Pope [17,18] and the Generalised Least Squares (GLS) method are mainly used.

Compared with the existing literature, this article presents two main contributions. Firstly, in contrast to studies that use temperature and precipitation as indicators of climate change, this study breaks new ground by using CO_2 emissions as the main determinant of CC. This choice is justified by the fact that all the IPCC reports [19–22] mainly measure climate change through CO_2 emissions. Secondly, given that most of the work on the impacts of climate change on the Cameroonian economy focuses on agriculture, forests and other sectors, this study aims to go further by looking at the impacts of climate change on agriculture and, by extension, on economic growth.

In the remainder of this article, we present a few stylized facts (2), a summary of the theoretical and empirical literature review (3), the methodological tools (4), the results of the estimates and the discussion (5) and the conclusion (6) to complete this analysis.

2. A few stylized facts

We will come back to the quantities of CO_2 emitted in Cameroon during the period under analysis and to the changes in agricultural production and economic growth in the country.

2.1. Continued increase in carbon dioxide emissions

Figure 1 below shows the evolution of CO_2 emissions in Cameroon over the period 1990–2020. The curve shows that CO_2 emissions are increasing over the period.

The quantities of CO_2 rose from 6966.2 kilotons in 1990 to 9928.4 kilotons in 2020, an increase of 2962.2 kilotons over the ten-year period. The increase in CO_2 emissions in Cameroon can be explained by several factors. Firstly, strong urbanisation. Since the 1980s, Cameroon has seen an increase in its population and a growth in industrial and commercial activities. This has led to a growing demand for energy, mainly from fossil sources such as oil, gas and coal, which are major emitters of CO_2 [23,24]. Secondly, the increase in the rate of deforestation. This is mainly due to the expansion of agriculture, logging and urbanisation. Deforestation (like land-use change) contributes to the release of large quantities of CO_2 stored in forest biomass, as well as reducing the capacity of remaining forests to absorb CO_2 from the atmosphere [25,26].

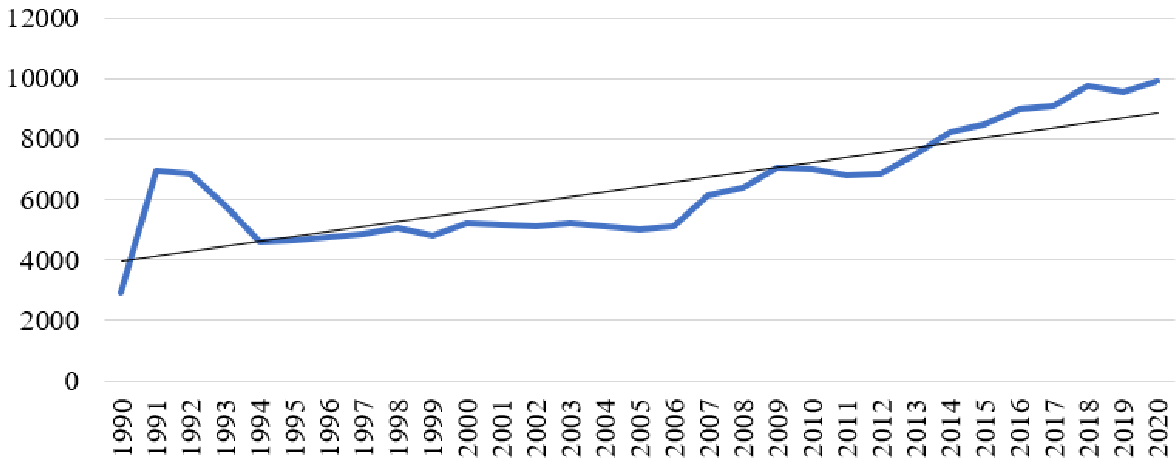

Figure 1. Evolution of CO_2 emissions (in kilotons) between 1990 and 2020 in Cameroon.

Source: Authors.

2.2. Trends in agricultural production

Figure 2 shows the evolution of the gross agricultural production index and agricultural value added over the period 1990–2020 in Cameroon. Analysis of the gross agricultural production curve reveals an upward trend over the period, from 34.75 kt in 1990 to 101.52 kt in 2020. Agricultural production in Cameroon has grown strongly, and has changed radically since the 1980s, with a reduction in the importance of traditional export crops (coffee, cocoa) in favor of food crops. According to FAOSTAT data, the value of food crops has risen sharply, from CFAF 240 billion in 1990 to CFAF 1631 billion in 2013. Over the same period, there was a less marked increase in cash crop production, rising from FCFA 179 billion to FCFA 538 billion [27]. **Figure 2** also shows that agricultural value added fell over the period, from 23.99% of *PIB* in 1990 to 19.49% of *PIB* in 2020.

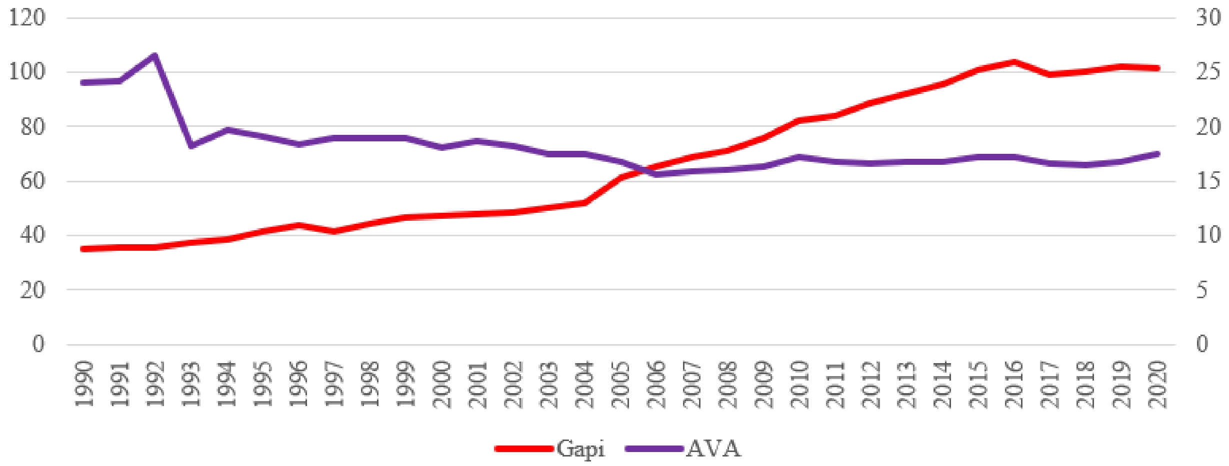

Figure 2. Trends in gross agricultural production index and agricultural value added between 1990 and 2020 in Cameroon.

Source: Authors.

2.3. Trends in economic growth

Figure 3 shows changes in GDP and the GDP growth rate over the period 1990–2020. The figure shows that economic growth in Cameroon was on an upward trend from 1993 to 2015, a trend that can be explained by major investment in wealth-creating infrastructure, particularly roads, ports and electricity grids. This growth phase was followed by a period of slowdown from 2015 onwards. This slowdown can be explained on the one hand by the secessionist crisis in the North-West and South-West regions, and on the other by the advent of the covid-19 pandemic, which brought economic activity to a halt worldwide.

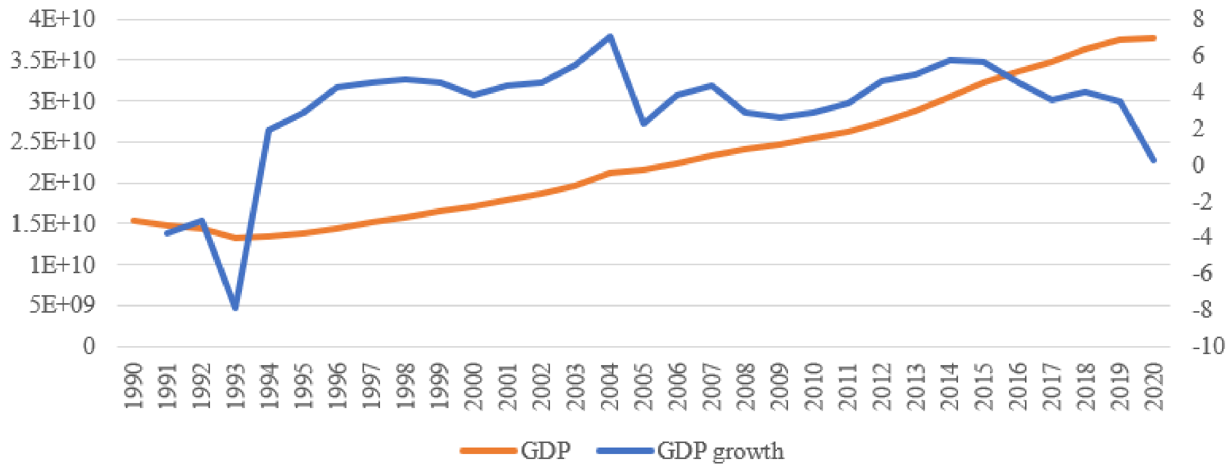

Figure 3. Change in GDP and its growth rate between 1990 and 2020.

Source: Authors.

3. Summary of the state of the art and theoretical position

A brief review of the literature will enable us in this section to return to the theoretical and empirical characterization of the relationships between climate change and agriculture on the one hand, and between climate change and economic growth on the other.

3.1. Theoretical summary

The theory of externalities finds a perfect application in the analysis of the impact of climate change on agricultural production and economic growth. Given that farmers' primary aim is to make private profits, their activities induce externalities, some of which contribute to the increase in greenhouse gases and CC. But the environmental externalities suffered by Cameroonian farmers are not solely the result of their own activities. Indeed, CC is considered to be a global public good, with no property rights. Herfindahl and Kneese [28] consider that the pollution of air and water, for example, is due to the fact that these elements are collective resources from which anyone can draw, without paying the price of acquiring them.

In the economics of climate change, GHG emissions are regarded as negative externalities. And the negative impacts caused by these GHGs and by CC constitute social costs for current and future generations. According to this logic, all markets fail in the presence of CC. The equilibrium to which the markets (national, regional, or global) lead are no longer Pareto optimums, because of the difference between the costs or benefits of the participants in these markets and the social costs [29,30]. For Baumol and Oates [31], external effects are the unwanted negative or positive impacts of the activities of one or more people on the activities of one or more other people. These effects lead to a shift in the production or consumption equilibrium. Moreover, for some externalities, such as climate change, their effects are global and persist over a very long period. Put simply, CC is an externality with dimensions that go beyond those seen in economic analysis: GHG emissions are a global phenomenon, they have a long-term impact, they involve risks and uncertainties, and they have the potential to bring about major and irreversible changes.

The Stern reports [1,32] on the economics of climate change are appreciable efforts, in that they provide quantified data on this CC issue. The 2006 report concludes that if no action is taken, the global costs and risks of climate change will be equivalent to a loss of at least 5% to 20% of annual Gross World Product (GWP). On the other hand, says Stern [32], the costs of action to reduce greenhouse gas emissions, i.e. to avoid the worst consequences of climate change, may be limited to only around 1% of global GDP each year.

3.2. Summary of empirical work

In this subsection, we will successively return to the empirical characterization of the CC and agriculture relationship on the one hand, and to the effects of CC on economic growth on the other hand.

3.2.1. Climate change and agriculture

Numerous empirical studies have been carried out to assess the impact of climate change on agriculture. Various typologies of these studies have been proposed (see the dossier published in the Review of Environmental Economics and Policy by Blanc and Reilly [33]. The choice of agricultural variables, i.e., those on which we seek to quantify the impact of climate change, enables us to differentiate between some of these studies. Some of the studies, carried out mainly by agronomists, environmental scientists and economists, focus on biophysical variables such as production, yield and total biomass [34]. Other work, carried out mainly by economists, focuses on variables expressed in monetary terms: Value of agricultural production, agricultural income or land value [35].

Three main approaches have emerged from this work [33,35]. The first approach, called the production function [36], is an experimental approach that attempts to measure the direct effects of a change in climate on the various crops and on input requirements (light, pesticides, herbicides, fertilizers, etc.). It is estimated using plant biophysical simulation models such as CERES [37] or SOYGRO [38]. The advantage of these experiments is that they make it possible to measure very precisely the mechanism by which crops respond to climate, by observing their behavior individually and controlling all the other variables likely to influence plant growth. What's more, these experiments make it possible to reproduce conditions that do not yet exist in nature, such as CO_2 fertilization. However, these experiments are unable to take into account the effects of indirect modifications to the environment in which the crops grow.

The second approach, the Ricardian or hedonic model developed by Mendelshon et al. [4], directly measures the effect of climate on land value and agricultural yield, using a cross-sectional study. This method is based on the assumption that markets are efficient, i.e., that the value of agricultural land reflects the present value of future income from the most productive farm. By looking at farmland prices in different environments, this approach implicitly studies a full range of possible adaptation strategies for farmers. In addition, this method makes it possible to capture the influence of economic, climatic and environmental factors on the value of agricultural land. Thus, the model is based on an analysis of the effect of climate change on the net income of farms, taking into account potential adaptations to climate change (indirect substitutions of inputs, introduction of new activities, etc.) [39]. In practice, this model has been used successfully in developed countries: The United States of America [4,40] and England [41]; in emerging countries: Vietnam [42], South Africa [43], India and Brazil [44]; in developing countries: Niger [45], Burkina Faso [39] and Cameroon [46,47].

The third and final approach developed by Deschênes and Greenstone [48] models the rational farmer and provides a biophysical response of plants to climate that is more realistic than that obtained with the Ricardian approach. Based on a panel data methodology, this third approach makes it possible to introduce specific individual and time effects. Then, by incorporating the use of climate variables, it makes it possible to respond to increasingly insistent recommendations in the economic literature [49].

Each of these three approaches has its limitations. The production function model is unable to take into account certain effects, such as an indirect change in the environment in which crops are grown (deterioration in land quality, increased insect populations due to heat, etc.). Furthermore, this approach tends to overestimate the influence of climate change on production, while underestimating the impact of the various adaptation options available to farmers [4,50]. The weaknesses of the Ricardian model stem, on the one hand, from its tendency to underestimate the damage to agriculture caused by climate change [51]. Secondly, the model assumes that farmers will adapt fully and efficiently, without taking any real account of the transition costs [52,53]. The Deschênes and Greenstone model attempts to resolve the limitations of the two previous approaches. However, this third approach poses the problem of calibrating and validating a robust statistical model.

Taking into account the type of data available to us, we adopt the production function model to estimate the effects of climate change on agricultural production in Cameroon.

3.2.2. Climate change and economic growth

All the bases of economic activity are affected by CC, including ecosystems, biodiversity, food and infrastructure. The areas and activities most sensitive to climate change include the agri-food industry, energy demand, hydroelectric and biomass energy production, forestry, construction and public works, health, fisheries, transport, etc.

Parry et al. [54] and Patt and Hess [55] have shown that climate change exacerbates existing pressures on ecosystems, accelerating their destruction and the loss of biodiversity. Hornbeck [56] revealed that the extreme weather events that hit the USA in the 1930s severely degraded the environment, leading to a fall in agricultural yields and putting many farmers out of work. For Ranger et al. [57] and the World Bank [58], CC affects all the sites on which infrastructures are built and the way they are designed. This requires additional infrastructure to be put in place to protect against climate change, such as sea defenses and flood defenses.

With regard to the effects of climate change on human capital, two main areas of human capital—education and health—have been extensively studied. Work by the UNDP [59] has shown that children born during the floods of the 1970s are 19% less likely to have attended primary school. Cuaresma [60] estimated that an increase in the risk of natural disasters reduces secondary school enrollment. In terms of health, Parry et al. [54] concluded that climate change exacerbates the occurrence of diseases such as malaria and cholera.

In terms of macroeconomic stability, some studies have estimated that the budgets of the various countries are under pressure, insofar as additional funds are needed each year to correct (sometimes urgently) the damage caused by CC. Heipertz and Nickel [61] have shown that the occurrence of natural disasters increases budgetary pressure through a temporary fall in revenue.

The search for empirical evidence on the relationship between climate change and economic growth has attracted the attention of many authors. Researchers have focused primarily on extreme weather events, which can have significant negative effects on economic growth. Nordhaus and Boyer [62] evaluated a negative relationship between temperature and per capita production. They also demonstrated that geographical factors largely explain the differences in income between Africa and the rest of the world. Dell et al. [63,64] have estimated that in poor countries, a 1°C increase in temperature in a given year will lead to a reduction in economic growth of 1.1 percentage points that year. Using annual data for 34 African countries over the period 1961 to 2009, Abidoye et al. [65] assessed the negative impact of climate change on economic growth in Africa. These authors demonstrated that a 1°C increase in temperature reduces economic growth by around 0.27 percentage points. Lanzafame [66] studied the effects of climate change on economic growth using data from 36 African countries over the period 1962 to 2000 using a staggered lag autoregressive model. It found negative short- and long-term relationships between temperature and per capita income growth. Using simulation models for the 2100 horizon, Mendelsohn [67] demonstrated that the impact of warmer temperatures only represents between 0.1% and 0.5% of GDP. For Barrios et al. [68], the effect of rising temperatures on agriculture is more serious in sub-Saharan Africa than in other developing countries. Using a co-integration analysis on Ethiopia, Ali [69] estimated a negative effect of rising temperatures on economic growth, and demonstrated that changes in the magnitude and variability of rainfall have positive long-term effects on economic growth. In contrast, Bernauer et al. [70], using global data for 1950–2004, concluded that the impact of climate change on economic growth is not robust.

4. Methodological tools

This section presents the empirical model, the estimation techniques and the data used.

4.1. The empirical model

For our analysis, we adopted a stochastic production function model developed by Just and Pope [17,18]. This model has been applied in several similar studies, such as Guntukula and Goyari [71], Saei et al. [72], Joshua et al. [73] and Boubacar [74]. The choice of this model is justified firstly by the virtual non-existence of a market for agricultural land in Cameroon and the difficulty of establishing (taking externalities into account) a method for calculating agricultural profits. And secondly, because of the limitations of the Ricardian methods of Deschênes and Greenstone, which tend to underestimate the impact of climate change and have problems with the calibration and validation of a robust statistical model.

In order to measure the effects of CO_2 emissions on the mean and variance of agricultural production and Gross Domestic Product, the stochastic production function suggested by Just and Pope [17,18] is decomposed into a deterministic function which links it firstly to outputs and secondly to the variability of these same outputs.

In general, the model looks like this:

$$Y = f(X, \beta) + h(\sqrt{X, \alpha})\varepsilon \quad (1)$$

where Y is agricultural output or PIB the and $f(X)$ is the mean production function (deterministic component of output), which relates X (set of independent explanatory variables such as climate and other inputs) to mean output with β which is the vector of parameters to be estimated. ε is the error term, which is heteroscedastic with zero mean. $h(X)$ is the variance function (stochastic component of output) that relates X to the standard deviation of output with α, which is the vector of parameters to be estimated and ε is the random error term that follows a normal distribution with zero mean and variance $\sigma 2$. Parameter estimation of the $f(X)$ function gives the average effect of the independent variables on output, while that of the $h(X)$ function gives the effect of the independent variables on the standard deviation of output.

$$E(Y) = f(x, \beta) \quad (2)$$

And,

$$Var(Y) = h2(x, \alpha) \tag{3}$$

The interpretation of the signs of the parameters of the $h(X)$ function is straightforward. If the marginal effect on the standard deviation of output of any independent variable is positive, then increasing the value of that variable increases the output risk. A negative sign implies that increasing the value of this variable reduces the production risk. With this formulation, the climatic variables and the other independent variables can each influence the mean and variance of production.

4.2. Model specification and estimation technique

The Cobb-Douglas production function and the linear form of the production function are chosen for the mean production function *f(X)*. The functional forms are compatible with Just and Pope's postulate of additive interaction between the mean and variance functions. The basic model is in linear form and is specified as follows:

$$Y_t = \exp\left(\alpha_0 + \sum_{k=1}^{k} \alpha_k X_{kt}\right) + \alpha_t Trend + \varepsilon_t \sqrt{\beta_0 + \sum_{m=1}^{m} \beta_m X_{mt}} \tag{4}$$

where Yt is the value of output (agricultural or PIB) in year t, Xkt represents the amount of input of factor k in year t and αj, j = 0, 1, …, k, are the parameters that need to be estimated. Xmt indicates the factors that can influence the level of risk and βm are the corresponding coefficients. ε is the stochastic disturbance term that follows a normal distribution (0, σ). Thus, expected output (frequently referred to as mean output) and output variance are determined by separate functions that are algebraically described as follows:

$$E(Y_t) = \exp\left(\alpha_0 + \alpha_t Trend + \sum_{k=1}^{k} \alpha_k X_{kt}\right) and\ V(Y_t) = \beta_0 + \beta_t Trend + \sum_{m=1}^{m} \beta_m X_{mt} \tag{5}$$

We assume that the production risk takes a heteroscedastic form in the production function. The second term on the right-hand side of Equation (4) can be interpreted as a heteroscedastic error term following in the estimation objective. The difference between the linear form and the Cobb-Douglas form is that the variables are ultimately put into logarithmic form. The best functional form for each crop depends on the results of diagnostic tests such as Wald, chi-square, log-likelihood, Akaike Information Criteria (AIC) and Bayesian Information Criteria (BIC).

The two main methods most commonly used for estimating Equation (5) are: Firstly, the Generalised Least Squares (GLS) method which involves three steps as suggested by Just and Pope [18] and secondly the Maximum Likelihood (ML) method introduced by Saha et al. [75]. In this study, we use the generalised least squares method. The latter has the advantage of correcting for zero correlation problems, which are not taken into account in estimates using the Ordinary Least Squares (OLS) method and the Maximum Likelihood method [76].

We will estimate the generalized least squares *(MCG)* model using STATA 15.0 software.

4.3. Data used and study variables

In order to analyze the impact of climate change on agriculture and economic growth, this study uses time series data for the period 1990–2020. The choice of study period and variables used is based on data availability and previous studies. The data used are mainly secondary data from the World Bank [77] and the FAO [78]. **Table 1** describes the main variables used in the study.

Table 1. Presentation of study variables.

Labels	Description of variables	Sources
Dependent variables		
Gapi	Gross agricultural production index	[78]
Gdp	Gross domestic product (in constant 2015 $)	[77]
The independent variable of interest		
Co_2	CO_2 emissions (in kilotons)	[77]
The control variables		
Acf	Agricultural capital formation	[78]
pcrop	Area of land under permanent cultivation (% of arable land)	[78]
empagr	Employment in the agricultural sector (% of total employment)	[77]
Trade	Trade openness (% of GDP)	[77]
Ava	Agricultural value added (% of GDP)	[77]
Mva	Manufacturing value added (% of GDP)	[77]
Vas	Value added in services (% of GDP)	[77]
Gfcf	Gross fixed capital formation (% of GDP)	[77]
Ide	Direct foreign investment	[77]

Source: Authors.

5. Results and discussion

5.1. Descriptive findings

Descriptive statistics for the study variables are given in **Table 2**. Real GDP over the study period ranged from $\$1.323 \times 10^{10}$ to $\$3.760 \times 10^{10}$, with an average of $\$2.285 \times 10^{10}$. Gross agricultural production has a minimum of 34.75% and a maximum of 103.88%, with an average of 65.747%. In terms of CO_2 emissions, Cameroon emitted an average of 6417.32 kilotons over the study period. Although the country remains a low emitter of CO_2, its emissions are increasing from year to year. An assessment of the area of permanently cultivated land shows that on average it is equal to 2.831% of the country's arable land, with a standard deviation of 0.338%. Employment in the agricultural sector varies between 43.304% and 68.411% of the active workforce, with an average of 58.956%. Agricultural value added, manufacturing value added and services value added represented an average of 18.187%, 14.912% and 48.051% of PIB respectively over the period under study. Trade openness varied between 26.159%

and 56.924%, with an average of 43.574%. Gross fixed capital formation averaged 18.194% of GDP.

Table 2. Descriptive statistics for study variables.

Variable	Obs	Average	Standard deviation	Min	Max
Co_2	31	6417.326	1804.804	2900	9928.4
Pba	31	65.747	24.938	34.75	103.88
GDP	31	2.285×10^{10}	7.873×10^{9}	1.323×10^{10}	3.760×10^{10}
Acf	31	261.491	165.232	35.459	580.925
Pcropland	31	2.831	0.338	2.539	3.279
Empagri	31	58.956	9.222	43.304	68.411
Ava	31	18.187	2.503	15.625	26.58
Mva	31	14.912	1.001	12.826	16.952
Vas	31	48.051	2.457	44.698	51.77
Trade	31	43.574	6.723	26.159	56.924
Gfcf	31	18.194	1.264	14.305	19.896

Source: Authors.

The correlation matrix for the variables in the study is given in **Table 3**. The table shows that CO_2 emissions are strongly and negatively correlated with gross agricultural production (0.862) and real GDP (0.882).

Table 3. Correlation matrix of study variables.

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
(1) Co_2	1.000										
(2) Pba	−0.862	1.000									
(3) GDP	−0.885	0.976	1.000								
(4) Acf	0.842	0.961	0.978	1.000							
(5) Pcropland	0.844	0.952	0.916	0.883	1.000						
(6) Empagri	−0.896	−0.989	−0.989	−0.964	−0.959	1.000					
(7) Ava	−0.312	−0.622	−0.560	−0.638	−0.459	0.544	1.000				
(8) Mva	−0.682	−0.583	−0.685	−0.619	−0.545	0.633	−0.040	1.000			
(9) Vas	0.779	0.921	0.884	0.862	0.892	−0.902	−0.635	−0.474	1.000		
(10) Trade	−0.018	0.271	0.186	0.269	0.185	−0.184	−0.447	−0.093	0.270	1.000	
(11) Gfcf	0.320	0.604	0.603	0.681	0.476	−0.562	−0.686	−0.330	0.510	0.599	1.000

Source: Authors.

5.2. Results of the econometric analysis

5.2.1. Results of variable stationarity analyses

In order to analyze the stationarity of the variables in the study, the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests were used to verify the stationarity of the series. The results of the statistical calculations (level test and first difference test) are presented in **Table 4** below.

This table shows that CO_2 emissions (lnco2), (lnacf), (lnempagri), agricultural value added (lnvag), value added in services (lnvas) and gross fixed capital formation (lnfbcf) are integrated to order 0 [I(0)], since they are stationary at the 1% level. On the other hand, we note that the gross agricultural production index (lnpba), GDP per capita (lnpib), the area of permanently cultivated land (lnpcropland), manufacturing value added (lnvam) and trade openness (lntrade) are integrated at order 1 [I(1)] because they are stationary in first difference at the 1% threshold. It should also be noted that the ADF and PP tests at level and in first difference leads to the same conclusions for all the variables in the study. In addition, the combination of the I(0) and I(1) variables suggests the existence of a cointegrating relationship between the different variables.

Table 4. Stationarity analysis of study variables.

Variables	Dickey Fuller test		Philip-Peron test		conclusion
	A level	**1st diff**	**A level**	**1st diff**	
Lnpba	−1.956 (0.6251)	−10.283*** (0.000)	1.417 (0.9972)	−11.168*** (0.0000)	I(1)
Lngdp	−1.755 (0.7261)	−7.480*** (0.0000)	−1.338 (0.6116)	−7.492*** (0.0000)	I(1)
Lnco2	−3.627** (0.0277)	-	−3.647** (0.0261)	-	I(0)
Lnacf	−7.223*** (0.0000)	-	−7.281*** (0.0000)	-	I(0)
Lnempagri	−5.652*** (0.0000)	-	−5.631*** (0.0000)	-	I(0)
Lnpcropland	−1.220 (0.9064)	−5.357*** (0.0000)	−1.483 (0.5418)	−5.410*** (0.0000)	I(1)
Lnava	−3.667** (0.0046)	-	−3.702 (0.0041)	-	I(0)
Lnmva	−1.273 (0.8945)	−5.906*** (0.0000)	0.357 (0.9798)	−2.163*** (0.0021)	I(1)
Lnvas	−2.977** (0.0371)	-	−3.105** (0.0262)	-	I(0)
Lntrade	−1.2223 (0.7890)	−6.001*** (0.0000)	−1.184 (0.6116)	−6.492*** (0.0000)	I(1)
Lngfcf	−3.223*** (0.0021)	-	−3.647** (0.0261)	-	I(0)

Note: Values in brackets are *p*-value and * (**) (***) indicate that the coefficient evaluated is significant at 10%, 5% and 1% respectively. Sources: Authors.

5.2.2. Analysis of the impact of climate change on agricultural production

Table 5 shows the coefficients obtained after estimating the average production function for agricultural products in the third stage of the stochastic production function estimation process. On the other hand, the production variance functions are obtained from the second stage of the estimation process of the Just and Pope [17,18] production function.

Analysis of the average production function shows that CO_2 emissions have a significant negative impact on agricultural production at the 5% threshold. This means that a 1% increase in CO_2 emissions reduces agricultural production by 7.4506%, all other things being equal. The negative influence of CO_2 emissions on agricultural production can be explained by the fact that an increase in CO_2 emissions leads to climate disruption, which in turn leads to an increase in temperatures, a variation in rainfall and an upsurge in natural disasters of climatic origin (flooding, drought, storms, etc.). This climate change is harmful to all agriculture in Cameroon, particularly in the Sudano-Sahelian agro-ecological zone. The negative impacts can be seen in lower yields, increased attacks by pests and other insects, and the destruction or even disappearance of small farms. Our results are in line with those of Defang et al. [79] and Molua [46], who estimate that climate change is having a negative impact on agricultural yields and farm income in Cameroon.

With regard to agricultural capital formation, our estimates allow us to conclude that this has a positive and significant influence on agricultural production at the 10% threshold. This means that an increase in agricultural capital increases gross agricultural production by 0.3259%.

With regard to the analysis of the variance function of agricultural production, two main results emerge from our analyses. Firstly, we estimate that a 1% increase in both CO_2 emissions and agricultural land increases the risk of gross agricultural production by 0.0318% and 0.1533% respectively. Secondly, a 1% increase in agricultural capital formation and agricultural employment, respectively reduces the risk of gross agricultural production by 0.1486% and 0.0037%.

Table 5. Results of the estimation of the average agricultural production function and its variance.

	Dependent variable: lnpba	
	Average output function	**Production variability**
Lnco2	−7.4506** (3.4275)	0.0318*** (0.0118)
Lnacf	0.3259* (0.7064)	−0.1486*** (0.0036)
lnempagri	−0.1389 (0.1423)	−0.0037*** (0.0007)
lnpcroland	0.5454 (1.8049)	0.1533*** (0.0130)
Constant	67.0217 (38.6957)	−1.1209*** (0.1650)
Number of observations	30	30

Note: Values in brackets are robust errors and * (**) (***) indicate that the coefficient evaluated is significant at 10%, 5% and 1% respectively. Source: Authors.

5.2.3. Impact of climate change on GDP in Cameroon

Table 6 shows the coefficients obtained after estimating the average GDP production function at the third stage of the stochastic production function estimation process. And on the other hand, the GDP variance function obtained from the second stage of the estimation process of the Just and Pope [17,18] production function.

The results of our analysis reveal that CO_2 emissions have a negative impact on GDP at the 5% threshold. This means that a 1% increase in CO_2 emissions leads to a 0.0090% reduction in GDP. This result can be explained by two main transmission mechanisms. Firstly, climate change disrupts the productive structure, particularly agricultural production, which is the engine of economic growth in Cameroon. Secondly, climate change induces additional production costs and adaptation costs that reduce the resources available for other productive investments. These results are consistent with those of Abidoye et al. [65], who show that climate change has a negative impact on economic growth in sub-Saharan African countries. Moreover, these results are similar to those of Ogbuabor and Egwuchukwu [16], who find that CO_2 emissions have a negative impact on Nigeria's GDP.

As other results, we estimate that agricultural value added, manufacturing value added, services value added and gross fixed capital formation positively and significantly affect GDP at the 5%, 1%, 1% and 5% thresholds over the analysis period. This means that a 1% increase in the value of these variables increases PIB by 0.0011%, 0.0044%, 0.0023% and 0.0021% respectively.

The analysis of the variance of PIB leads to two main results. Firstly, we observe that a 1% increase in CO_2 emissions and trade openness leads to an increase in the risk of GDP formation of 0.0022% and 0.0004% respectively. Secondly, the results show that a 1% increase in agricultural value added, manufacturing value added, services value added and gross fixed capital formation reduces the risk of GDP formation by 0.0003%, 0.0012%, 0.0006% and 0.0006% respectively.

The positive relationship between CO_2 emissions and PIB formation risk can be explained by the fact that climate change caused by greenhouse gas emissions affects many sectors that are important for GDP formation, including agriculture [80,81], industries [82] and infrastructure [83]. As for the positive influence of trade openness on the risk of PIB formation, we can say that this can be explained by the fact that trade openness, characterized by a domination of imports over exports weakens the country's production capacity and consequently increases the risk of GDP formation [84].

The negative influence of agricultural, manufacturing and services value added on the variability of GDP formation can be explained by the fact that GDP can be understood as the sum of the economy's value added. Consequently, an increase in agricultural, manufacturing and services value added over time leads to a reduction in fluctuations in GDP formation [85].

Table 6. Results of the estimation of the mean function and its variance.

	Dependent variable: lnpib	
	Average output function	**Production variability**
Lnco2	−0.0090** (0.0044)	0.0022*** (0.000)
Lnava	0.0011** (0.0005)	−0.0003*** (0.0000)
Lnmva	0.0044*** (0.0011)	−0.0012*** (0.0000)
Lnvas	0.0023*** (0.0005)	−0.0006*** (0.0000)

Table 6. (*Continued*).

	Dependent variable: lnpib	
	Average output function	**Production variability**
Lntrade	−0.0001 (0.0001)	0.0004*** (0.1650)
LnGfcf	0.0021** (0.0009)	−0.0006*** (0.0130)
Constant	3.0308*** (0.0623)	0.7993*** (0.0001)
Number of observations	30	30

Note: Values in brackets are robust errors and * (**) (***) indicate that the coefficient evaluated is significant at 10%, 5% and 1% respectively. Source: Authors.

5.2.4. Robustness analysis

The use of CO_2 emissions as an indicator of climate change has a number of limitations, particularly with regard to their impact on agricultural production and economic growth. Although CO_2 is an important greenhouse gas, it does not reflect short-term climate variability, which can directly affect agricultural yields and production in the main economic sectors. Indeed, extreme events such as droughts and floods can occur independently of CO_2 levels [11,86]. In addition, temperature plays a crucial role in plant growth, and rising temperatures can lead to heat stress in crops. Rainfall patterns are also essential for understanding the impact of climate change on agricultural production and economic growth [15]. Variations in the amount and distribution of rainfall can influence the availability of water for crop growth. Therefore, for a more complete analysis of the effects of climate change on agricultural production and economic growth, it seems crucial to explore other indicators of climate change such as temperature and rainfall, which offer a more nuanced perspective of the conditions that farmers face.

Table 7 presents the results of the estimates of the mean agricultural production function and the stochastic production variance function using mean annual temperatures and total precipitation as proxies for climate change. Three main results emerge from this analysis. Firstly, temperatures have a significant negative influence on agricultural production at the 5% level. This means that a 1% increase in temperature reduces agricultural production by 0.0868%, all other things being equal. This result can be explained by the fact that the increase in temperature will reduce crop yields by increasing water stress, which will lead to a drop in agricultural production. This finding is similar to those of Defang et al. [79] who find that temperatures negatively impact agricultural production in the department of Muyuka in Cameroon. Furthermore, these results are also in line with those of Joshua et al. [73] who show that temperatures have a negative impact on certain agricultural crops in Nigeria.

Secondly, the estimate of production variability shows that temperatures significantly increase the risk of agricultural production in Cameroon at the 1% threshold. A 1% increase in temperature increases the risk of agricultural production by 0.0252%. This would mean that an increase in temperature could increase the frequency of extreme climatic events such as droughts, which could lead to disruptions in agricultural production in Cameroon.

Thirdly, the results show that rainfall has no significant influence on the average agricultural production function and the variability of agricultural production.

Table 7. Results of the estimations of the influence of temperature and rainfall on agricultural production.

	Dependent variable: lnpba	
	Average output function	**Production variability**
Ln temp	−0.0868** (0.1224)	0.0252*** (0.2923)
Lnprecip	−0.0130 (2.8570)	0.0114 (0.0391)
Lnacf	0.1503*** (0.0038)	0.0523*** (0.0093)
Lnempagri	−0.0024*** (0.0005)	−0.0028** (0.0014)
Lnpcroland	0.1610*** (0.0133)	0.0755** (0.0314)
Constant	1.6655*** (0.4262)	1.1003*** (1.0185)
Number of observations	31	31

Note: Values in brackets are robust errors and * (**) (***) indicate that the coefficient evaluated is significant at 10%, 5% and 1% respectively. Source: Authors.

Table 8 presents the results of the estimates of the influence of temperature and precipitation on GDP. Two main results emerge from the analyses. Firstly, interpretation of the coefficients shows that temperature and precipitation exert negative and significant influences on average GDP at the 1% threshold, respectively. This would mean that a 1% increase in temperature and precipitation would reduce GDP by around 0.0017% and 0.0093% respectively. Indeed, increases in precipitation and temperature can have negative impacts on a country’s economy, leading to a reduction in GDP. On the one hand, increased precipitation can lead to flooding, landslides and infrastructure damage, which can disrupt economic activities and reduce production. Excessive rainfall can also affect people’s health, leading to additional healthcare costs and reduced productivity. On the other hand, rising temperatures can lead to a reduction in productivity in productive sectors such as agriculture, construction and services, as workers can be less efficient in extreme heat conditions. These results are similar to those of [15] who show that temperatures have a negative influence on GDP.

Secondly, the estimate of production variability shows that temperature and rainfall significantly increase the variability of GDP in Cameroon at the 1% threshold. A 1% increase in temperature and rainfall increases the risk of agricultural production by 0.0036% and 0.0025% respectively. This would mean that the increase in extreme weather events (droughts, floods, storms, etc.) caused by climate change increases the risk of achieving GDP targets. Excessive rainfall and high temperatures can lead to disruptions in supply chains, damage to infrastructure and production losses, which can cause significant fluctuations in GDP. Extreme weather events can also affect investor and consumer confidence, which can lead to variations in interest rates, share prices and exchange rates.

Table 8. Results of the estimations of the influence of temperature and precipitation on GDP.

	Dependent variable: lnpib	
	Average output function	**Production variability**
Lntemp	−0.0017*** (0.0687)	0.0036*** (0.0001)
Lnprecip	−0.0093*** (0.0097)	0.0025*** (0.0001)
Lnava	−0.0014** (0.0005)	−0.0003*** (0.0654)
Lnmva	−0.0057*** (0.0011)	−0.0015*** (0.0043)
Lnvas	0.0030*** (0.0005)	0.0008*** (0.0224)
Lntrade	−0.0002 (0.0001)	−0.0005*** (0.0023)
LnGfcf	0.0016 (0.0009)	−0.0004*** (0.0130)
Constant	3.0705*** (0.0623)	0.8115*** (0.0001)
Number of observations	31	31

Note: Values in brackets are robust errors and * (**) (***) indicate that the coefficient evaluated is significant at 10%, 5% and 1% respectively. Source: Authors.

6. Conclusion

For the time being, and for several decades to come, climate change will continue to be a preoccupation for many decision-makers and researchers. Its close negative correlation with economic growth and its detrimental effects on people's quality of life make it a source of many questions. In this study, we analyzed and assessed the impact of climate change on agricultural production and economic growth in Cameroon. To achieve this dual objective, we used a stochastic production function model developed by Just and Pope [17,18]. We also used CO_2 emissions as a proxy for climate change and evaluated its impact on gross agricultural production index and real GDP growth over the period from 1990 to 2020. The results of our study confirm: (i) The existence of an unambiguous negative link between climate change and agricultural production. A 1% increase in CO_2 emissions reduces the gross agricultural production by 7.4506%; (ii) climate change clearly has a negative impact on economic growth. A 1% increase in CO_2 emissions reduces economic growth by 0.0090%. For robustness, we explored other climate indicators such as precipitation and temperature. The results show that for temperatures, a 1% increase reduces agricultural production by 0.0868% and economic growth by 0.0017%. For rainfall, a 1% increase reduces GDP growth by 0.0093%. These results lead us to formulate a number of economic policy recommendations. Generally speaking, we recommend that decision-makers promote the dissemination of climatic information to farmers, so that they can incorporate it into their decision-making. In addition, we recommend that irrigation systems be improved to compensate for water shortages in drought-prone areas. In addition, we recommend that decision-makers invest in sustainable infrastructure and early warning systems, introduce strict regulations on greenhouse gas emissions and support research into climate change. By way of a proposal for future research, these results lead us to other questions. What can be done to mitigate the adverse effects of climate change on agricultural production and economic growth?

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Notes

1 The range mentioned by Stern does not give an indication of uncertainty, but only the central values to be considered according to the extent of the phenomena we are interested in: At 5%, only damage to production and income-generating activities (in particular the exploitation of natural resources) is considered. Integrating losses in human life and ecological losses (ecological services) more than doubles the percentage. Taking into account more extreme assumptions about climate sensitivity and the existence of positive feedbacks that amplify imbalances (methane emissions from thawed permafrost, reduced absorption by the oceans, etc.) increases the cost of damage to 14%. Finally, recognition of the fact that the poorest populations in the least developed countries will be proportionally the hardest hit—they are more dependent on natural conditions to satisfy their basic needs, they have less capacity to adapt and they are objectively located in regions that will be harder hit physically—leads to costs of around 20%.

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