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Vulnerability of Agricultural Employment and Climate Change in WAEMU Countries

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Abstract : This article examines the effect of climate change on rural agricultural employment in the countries of the West African Economic and Monetary Union (WAEMU), with a panel analysis covering the period from 2000 to 2021. We use Romer's (1986) endogenous growth model, enriched with the Cobb-Douglass model by drawing on the Dynamic Integrated Climate-Economy (DICE) model by (Nordhaus, 1992 ; 2013). Rising CO_2 emissions, drought and floods are leading to a sharp loss of agricultural jobs, especially in rural areas. However, investments in clean technologies help farmers to adapt and preserve some jobs linked to cash and seasonal crops. These results highlight the importance of proactive policies to support agricultural employment, reconciling economic growth, environmental protection and social welfare in the region.

Keywords: *Agricultural Employment, Climate Change, Panel, Economic Growth, WAEMU.*

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I. INTRODUCTION

Nearly half the world's population lives in rural areas, and agriculture accounts for 27% of global employment, making it the second largest employer sector (WB, 2023 ; Malanski, 2021). Its imortance varies from region to region: in Africa, it accounts for over 50% of jobs, compared with less than 10% in Europe, including 3% in France (Roemmich and al., 2019; WB, 2021). In West Africa, the food economy is the leading employer, accounting for 66% of jobs, including over 60% in the WAEMU (Heinrigs and Heo, 2018 ; Allen and al., 2018 ; WB, 2021). In sub-Saharan Africa, agriculture accounted for 52% of total employment in 2020, compared with 59% in 1991, a drop of four points due to climate change (Gbemenou and al., 2020). Despite this preponderance, its contribution to African GDP remains low (17.5% in 2020) (Magrin and al., 2022).

Indeed, real GDP per capita in Africa declined, particularly during the 1980s and 1990s, due to political instability, economic crises and droughts linked to climate change. In sub-Saharan Africa, the labor market remains precarious, with 72% of jobs vulnerable and between 34% and 72% informal (Dumas and al., 2022). In the WAEMU, agriculture employs around 60% of the working population and contributes 30% of regional GDP (World Bank, 2021), underlining its crucial role despite these challenges. However, WAEMU's agricultural sector is strongly impacted by climate change (Bouramdane, 2023 ; Bougma and al., 2024). Since the 1980s, average temperatures have risen by 1.5°C, leading to prolonged drought and more frequent flooding (Poirier, 2022). These upheavals have reduced agricultural productivity by 20% in recent decades, with losses expected to reach 30% by 2050 (World Bank, 2021). Without appropriate measures, between 737 million and 1.2 billion people could be affected (FAO, 2018 ; Henry, 2023 ; Kohnert, 2024). Falling farm incomes accentuate job losses, particularly among young farmers (Laroche-Dupraz and Ridier, 2021 ; Chatellier, 2024 ; Mahamadou and al., 2023).

Agricultural employment in the WAEMU remains precarious, dominated by informality and seasonality (Parmesan and al., 2022). Young people, who account for 65% of the population, are particularly hard hit, migrating to cities or abroad in search of economic opportunities (ILO, 2022 ; WAEMU and LE DEFICIT, 2022 ; Lane and al., 2023). This phenomenon of climatic migration has become a common response to the degradation of agricultural land. In Burkina Faso, 10% of rural youth leave their region each year for more stable employment (ILO, 2022). Smallholders, representing 80% of farmers, are the most vulnerable (FAO and Jiang, 2022 ; FAO, 2022). This precariousness of agricultural employment compromises the economic and social stability of WAEMU countries, threatening their sustainable development.

Faced with this growing vulnerability, WAEMU governments have adopted policies aimed at strengthening agricultural resilience, diversifying sources of income and securing employment to reduce the impacts of climate change. Despite these efforts, climate change continues to have a negative impact on agricultural employment. This

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article analyzes how climate change is increasing the vulnerability of agricultural employment in the WAEMU and explores mitigation measures to strengthen the resilience of rural populations in the face of these challenges.

The remainder of this article will focus on the following points. Section 2 presents the literature review. Section 3 presents the methodology and model. Section 4 describes the data used for this research. Section 5 discusses the results. Finally, section 6 provides conclusions and policy implications.

II. LITERATURE REVIEW

Agriculture is a pillar of economic growth, particularly in developing countries (Mellor, 1966). Its strong dependence on natural conditions led researchers in the 1980s to examine the impact of climate change on agricultural employment (Parry, 1962). These studies showed that this sector, which is vulnerable to climatic variations, suffers disruptions that directly affect production and employment (Rosenzweig and Parry, 1994). Preserving agricultural jobs is essential to guarantee food security and sustainable economic development. Various economic theories prior to 1999 emphasize the central role of agriculture in growth, and stress the need to protect these jobs to avoid economic imbalances (Todaro, 1996). Early economic theories emphasized the vulnerability of agricultural systems, highlighting the impact of climatic variations on the natural resources essential for production (Mendelsohn and al., 1994 ; Kaufmann, 1998). The availability of fertile land and water resources becomes uncertain under the impact of climate change, compromising the stability of agricultural employment. The theory of climatic impact on agricultural productivity (Adams and al., 1990 ; Sotamenou and Saleufeumeni, 2013) shows that variations in temperature and precipitation reduce crop productivity, particularly in rain-fed agricultural systems. This in turn reduces the demand for labor, accentuating the precariousness of agricultural employment. Several empirical studies, notably in the United States, confirm this correlation between productivity and agricultural employment (Adams and al., 1990).

Research in the 1990s highlighted the growing precariousness of agricultural employment in the face of climatic variations. Tol and al (1998) show that the instability of farm incomes, due to weather conditions, has a particular impact on seasonal and temporary workers. The latter, often unskilled and poorly paid, are subject to heightened insecurity, exacerbated by the flexibility of employment contracts, which enables employers to reduce their workforce in the event of climatic shocks. The impact of climate change on agricultural productivity is also driving rural-urban migration (Rosenzweig and Parry, 1994), revealing the agricultural sector's inability to maintain stable employment. This migration puts pressure on non-agricultural sectors, accentuating economic imbalances. According to Dercon (2011), countries that invest in resilient infrastructure and sustainable agricultural practices are more likely to maintain long-term growth. Sachs and Warner (1995) confirm that tropical economies are particularly vulnerable to climatic shocks, hence the need for policies to protect agricultural jobs. Lewis's duality model (1954) underlines the key role of the agricultural sector in economic development. He warns against neglecting this sector, which is essential to the subsistence of rural populations. Nurkse (1953), in his theory of balanced development, stresses the importance of increased productivity in agriculture to stimulate demand in other sectors. If agricultural jobs are threatened by climate change, economic contraction becomes inevitable. Protecting agricultural jobs is therefore crucial to ensuring harmonious development and avoiding structural imbalances. Kuznets' (1966) environmental curve underlines the fact that initial economic growth leads to environmental degradation, before an income threshold encourages sustainable investment. In the WAEMU, where agriculture remains essential, climate change jeopardizes agricultural jobs and slows growth. Kuznets' theory therefore suggests climate adaptation strategies for sustainable growth.

Johnston and Mellor (1961) show that agriculture generates demand for other sectors, such as processing, transport and financial services. Any disruption to the agricultural sector, due to climate change, has macroeconomic repercussions. Protecting these jobs is therefore crucial to economic stability. Rostow (1960) stresses the importance of agriculture in the early stages of development, as increased productivity generates a surplus that can be reinvested in industry. However, the loss of agricultural jobs due to climate-related factors slows down this transition. Schultz (1964) points to the rationality of farmers and the need to invest in education and technology. However, these advances are threatened if agricultural jobs disappear. Schultz therefore advocates greater resilience in agricultural systems to preserve the sector's contribution to growth. The theories of Lewis (1954), Nurkse (1953), Kuznets (1966), Johnston and Mellor (1961), Rostow (1960) and Schultz (1964) converge towards the same conclusion : agriculture is a key driver of development. In the face of climate change, protecting agricultural jobs is essential to ensure balanced and sustainable economic development.

There is growing interest in the impacts of climate change on agricultural employment. Adebayo and al. (2021) show that droughts and floods reduce agricultural productivity and labor demand, underlining the importance of climate resilience. In sub-Saharan Africa, Rocco and al. (2022) reveal that agricultural workers suffer increased precariousness due to extreme climatic events, leading to seasonal unemployment and income instability. In Kenya, Kurgat and al (2020) report that rising temperatures and rainfall variability are reducing yields and agricultural labor. In India, Karmakar and al. (2021) find that climate fluctuations trigger seasonal migration to cities, increasing pressure on non-agricultural employment. Desalegn and al (2023), studying several developing countries, show that climate change aggravates the vulnerability of agricultural jobs by affecting production and income. They recommend adaptation policies, such as irrigation and resilient farming techniques. Nyasimi and al (2020) highlight the vulnerability of small-scale farmers in East Africa, who are exposed to job losses due to their dependence on climatic conditions. Arshad

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and al. (2022) analyze the role of agricultural policies in South Asia, concluding that appropriate measures can reduce worker vulnerability and secure employment in times of climatic stress. These studies converge on the same conclusion : governance and adaptation strategies are essential to protect agricultural employment in the face of climate change. Agriculture remains a major source of employment and income in developing countries, playing an essential role in economic growth. However, in the face of the challenges posed by climate change, preserving these jobs is crucial. Kamau and al (2021) point out that agriculture can generate sustainable employment, strengthening the economic resilience of rural communities. Furthermore, Tschakert and al. (2020) stress the importance of maintaining these jobs to guarantee food security and mitigate the effects of climate change through sustainable agricultural practices.

Agricultural innovation also helps to protect jobs. Haan and al (2023) show that the adoption of agroecological practices improves productivity while reducing greenhouse gas emissions. Furthermore, the analysis of Oduro and al. (2022) shows that each agricultural job generates opportunities in related sectors, amplifying its economic impact. With this in mind, Wang and al. (2021) point out that policies to support agricultural employment are essential for reducing poverty and fostering economic development. Agricultural jobs also play a major social role. Adetunji and al. (2020) highlight their contribution to the emancipation of women and the reduction of gender inequalities. In the WAEMU region, where 60% of the population depends on agriculture (Faye and al., 2020), these jobs boost productivity and are an essential lever for growth (Doumbia and al., 2021). The integration of modern agricultural technologies improves the resilience of these jobs to climatic hazards (N'Diaye and al., 2022), notably through conservation agriculture and efficient irrigation (Sanogo and al., 2021). Finally, Sarr and al. (2023) highlight the potential of agricultural jobs to reduce economic inequalities. Investing in agriculture remains a key growth driver for WAEMU (Fofana and al., 2022), requiring appropriate public policies to promote sustainable practices and protect agricultural employment from the effects of climate change.

III. METHODOLOGY AND ESTIMATION METHOD

A. Methodology

➢ *Economic Growth Aspect*

The aim of this study is to identify the effect of climate change on agricultural employment in WAEMU countries. To illustrate the process by which climate change affects agricultural employment, we consider the Cobb-Douglas (1928), Solow (1956) and new endogenous growth theories (Romer, 1986) economic growth function, presented as follows:

$$Y_{it} = A_{it}\, L_{it}^{\alpha}\, K_{it}^{\beta} \tag{1}$$

Y_{it} represents the quantity produced (GDP) in country i at period t, K_{it} is the capital factor, L_{it} is employment, A_{it} denotes technology, α and β are the elasticities of labor and capital respectively with respect to output. Dividing equation 1 by Lit, we obtain a new equation 2 which highlights the reduction in economic growth through the fall in agricultural employment (indirect effect of climate change on economic growth).

We have :

$$y_{it} = a_{it}\, k_{it}^{\beta} \tag{2}$$

With y_{it} labor productivity and k_{it} capital intensity. Climate change can therefore reduce economic growth measured by output (Y_{it}) through labor productivity (y_{it}) (Zhang and al., 2018 ; Huang and al., 2020). Environmental factors linked to climate change, such as high temperatures, floods and degradations impact labor productivity by inducing among agricultural workers, low incomes as well as increased drudgery of agricultural work (Hancock and al., 2007) which sometimes push these farmers to leave this sector of activity to find themselves unemployed due to the effects of climate change. However, if we consider net output Q_{it} equal to gross output Y_{it} adjusted for economic damages G_{it} linked to the agricultural sector, in particular agricultural employment, and mitigation costs $\wedge_{it}$ linked to climate change, taking these adjustments into account leads to a modification of the Cobb-Douglas production function (equation 1) as follows :

$$Q_{it} = G_{it}\,[1 - \wedge_{it}]\, Y_{it} \tag{3}$$

$$Q_{it} = G_{it}\,[1 - \wedge_{it}]\, A_{it}\, L_{it}^{\alpha}\, K_{it}^{\beta} \tag{4}$$

Taking the logarithm, we obtain the following relationship according to (Trinnou, 2022):

$$lnQ_{it} = ln\, G_{it} + [1 - \wedge_{it}]lnA_{it} + \alpha lnL_{it} + \beta lnK_{it} \tag{5}$$

With $(1 - \wedge_{it})$ the direct elasticity of technology, measuring the effect of climate change on economic growth in country i at period t.

➢ *Aspect Environnemental*

The environmental damage function considered is a quadratic function (Trinnou, 2022 ; Mourad and al., 2022 ; Mroué and al., 2023) of the global average temperature T_{AT}.

$$\Psi(t) = 1 - [\beta_1 T_{AT}(t) + \beta_2 T_{AT}(t)^2] \tag{6}$$

With β_1 and β_2 parameters.

The emission reduction cost equation ($\wedge(t)$) depends on the emission reduction rate $\mu(t)$ (Meleux and al., 2022 ; Génermont and al., 2023). This cost function is convex, reflecting the increase in the marginal cost of climate abatement as the rate of climate abatement increases in the agricultural sector.

$$\wedge(t) = \theta_1(t)\mu(t)^{\theta 2} \tag{7}$$

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In the economic and environmental literature, GHG emissions GES ($E(t)$), come from two sources, namely emissions from industrial activities ($E_{Ind}(t)$), considered as endogenous and other exogenous emissions, in this case, those resulting from soil warming ($E_{\text{aut}}(t)$). The latter source has direct consequences on agricultural activities, leading to a drop in agricultural productivity (Boureima, 2021), a drop in farm income (Laroche-Dupraz and Ridier, 2021 ; Jeanneaux and Velay, 2021) and the abandonment of farming activities. Hence the loss of agricultural jobs as a result of climate change. These different sources of emissions can be formalized as follows:

$$E(t) = E_{Ind}(t) + E_{\text{aut}}(t) \tag{8}$$

Emissions from other sources $E_{\text{aut}}(t)$, such as rising temperatures and warming of the earth's surface, are determined by multiplying an exogenous level of carbon intensity, $\sigma(t)$ by gross production Y_{it}, while taking into account the rate of reduction of these emissions $\mu(t)$ (Faïhun, 2024). Climate change takes the form of rising temperatures and warming ($E_{\text{aut}}(t)$) of the earth's surface, with a direct effect on agricultural employment (Stern, 2007, 2016). The following structural equations highlight the basic relationship between GHG concentrations, radiative forces (Burke and al., 2015 ; IPCC, 2021), and the dynamics of climate change in relation to the destruction of agricultural jobs in the agricultural sector in the WAEMU zone, which represents the economic lung of most developing countries.

$$E_{\text{aut}}(t) = \sigma(t)[1 - \mu(t)]Y_{it} \tag{9}$$

$$E_{\text{aut}}(t) = \sigma(t)[1 - \mu(t)]\, A_{it}\, L_{it}^{\alpha}\, K_{it}^{\beta} \tag{10}$$

Generally speaking, the formalization of Nordhaus' Dynamic Integrated Climate-Economy (DICE) model (1992, 2013) highlights the mechanism for capturing the interaction between climate change and agricultural employment vulnerability: In the absence of mitigation measures $\Lambda(t)$ (equation 7) in each country i according to the time t of emissions, those of GHG ($E(t)$) induce accumulations in the atmosphere. These accumulations lead to harmful effects on the environment, including a rise in average temperature. This rise in temperature causes damage to economic variables, such as total production (rising from $Y(t)$ to $G(t)$), of which agricultural activities are an important part, and consequently to social welfare, of which agricultural employment is a fundamental priority in developing economies. Formally, we have :

$$Y_{it} = A_{it}\, L_{it}^{\alpha}\, K_{it}^{\beta}$$

$$Q_{it} = G_{it}\, [1 - \Lambda_{it}]\, A_{it}\, L_{it}^{\alpha}\, K_{it}^{\beta}$$

Taking the logarithm, we obtain

$$lnQ_{it} = ln\, G_{it} + [1 - \Lambda_{it}]lnA_{it} + \alpha lnL_{it} + \beta lnK_{it} \tag{11}$$

This model provides an integrated framework for analyzing the impact of climate change on economic variables. Using this theoretical foundation, we estimate this equation using the panel model used to analyze the impact of climate change on agricultural employment in the WAEMU zone.

B. Estimation Method

An extensive literature explores the impact of climate change and adaptation measures in developing countries (Thornton and al., 2014 ; Millner and Dietz, 2015). Arora and Rada (2020) classify methodologies into two categories: partial equilibrium and general equilibrium approaches (Sawadogo and al., 2021). In West Africa, several works analyze the vulnerability of agricultural jobs to climate change (Williams and al., 2018; Bakhtache and al., 2023; Alfidi and al., 2024), identifying impacts on communities and adaptation strategies adapted to a context of economic vulnerability. The partial equilibrium approach focuses on regional agricultural production (Balaka and al., 2023; Bouramdane, 2023), while the general equilibrium integrates the upstream and downstream effects of a climate shock on agriculture. Two main methods are used to analyze these effects: the deterministic approach and the stochastic approach. Some research adopts a deterministic approach to studying the climatic impact on agriculture (Calzadilla and al., 2013; Gebreegziabher and al., 2015). However, analysis of the direct link between agricultural employment and climate change remains underdeveloped, as does specific modeling of these effects in contemporary economic and social research. The analysis of the vulnerability of agricultural jobs to climate change in the WAEMU can be deepened using the panel model (Doumbia and al., 2021; Gnedeka and al., 2023; Fall and al., 2023). However, this model, although frequently used with fixed or random effects, remains little exploited to establish causal links between employment and climate change. We first mobilize a fixed-effects model (Ochou and Quirion, 2022; Dandonougbo and al., 2020) on panel data to capture inter- and intra-country variations, taking into account unobserved specific effects. Next, the GMM estimator (Asongu and Odhiambo, 2020) is used to identify sources of endogeneity by incorporating random variables as instruments. This approach handles unobserved heterogeneity, omitted variables and simultaneity in regressions (Boateng and al., 2018). The GMM estimator also corrects for bias in the difference estimator (Arellano and Bond, 1991) and takes into account variation between countries. However, it is crucial to guarantee the validity of the instruments and avoid overloading them. Once the model has been justified, the following subsection will present results and discussions. Assuming that output growth depends on the weight of agricultural employment in the economy, we obtain:

$$Y_{it} = f(X_{it}) \tag{12}$$

Where Y_{it} is the level of production in country i at period t, and X_{it} is the share of agricultural employment in total employment in the country concerned. However, these jobs alone cannot explain economic growth. For this reason, we retain a set of control variables in addition to this variable of interest. Given that the most important and fastest-growing sector in the WAEMU countries is agriculture, its value added is retained as the variable of interest. Equation 1, augmented

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by the set Z_{it} of control variables, then by the random term with i the country identifier and the time identifier, becomes according to Kouadio (2020). The selected model is built as follows:

$$Y_{it} = \alpha_0 + \alpha_i X_{i,t} + \delta_i Z_{it} + \varepsilon_{it} \quad (13)$$

$$1 \leq i \leq n\ ,\ 1 \leq t \leq T\ ,\ n=8\ ;\ T=21$$

The vulnerability of agricultural employment to climate change is closely linked to the theory of socio-economic vulnerability, which is based on the concepts of sustainable development and climate adaptation.

IV. DATA AND VARIABLE DESCRIPTIONS

This section is devoted to presenting the data and variables involved in our research. The data collected for the various variables in the model come from the World Bank's Word Development Indicators database and from BCEAO. They cover the period 2000 - 2022. The sample is made up of the eight (08) countries of the Economic Community of West African States (WAEMU). In order to analyze the relationship between employment, economic growth and climate change in vulnerable regions of the WAEMU zone, it is essential to clearly define the variables used in this research.

- Employment in agriculture (EAGR) represents the proportion of the working population employed in this sector, estimated according to International Labor Organization (ILO) models. ▪CO_2 emissions per capita (ECO2QPPA) assesses the average amount of carbon dioxide emitted per individual in each of the WAEMU countries.
- The proportion of CO_2 emissions from electricity and heat production (ECO2cb) indicates the share of fuel combustion associated with these energy activities.
- The percentage of methane emissions from the energy sector (EMAE) highlights this source's contribution to overall methane emissions.
- Fertilizer consumption (CENG) expresses the quantity of fertilizer used per hectare of arable land, reflecting the intensity of agricultural practices.
- The quantity of nitrous oxide emissions (ÉPON) is measured in thousands of tons of CO_2 equivalent, and is an indicator of emissions of this greenhouse gas.
- Emissions of nitrous oxide in the energy sector (EPSE) specifically assess this sector's contribution to emissions of this pollutant.
- The rural population growth rate (CPRU) indicates the annual variation in the number of people living in rural areas.
- The real agricultural GDP growth rate (TPIB) measures the percentage change in value added generated by the agricultural sector, adjusted for inflation.

V. RESULTS AND DISCUSSION

A. Descriptive Statistics

Table 1 sheds light on the vulnerability of agricultural employment to climate change in West Africa, particularly in the WAEMU. Agriculture, which employs on average 57.33% of the working population, plays a central role in these economies. However, the wide dispersion of values (standard deviation 16.02; min: 22.24%, max: 88.61%) reflects structural differences between countries, influenced by varying levels of economic diversification. CO2 emissions per capita (ECO2QPPA), with an average of 0.259 tonnes and a maximum of 0.769 tonnes, illustrate the impact of agricultural and industrial practices on the environment. Agricultural productivity (EPSE), with an average of 99.93 (min: 37.8, max: 288.4), reflects inequalities in access to inputs, modern technology and infrastructure. Similarly, energy costs (CENG), with an average of 12.97 and marked variations, show the challenges linked to the sector's competitiveness and resilience. GDP (TPIB) shows average growth of 3.23%, but with extreme volatility (-26.40% to 21.06%), highlighting high agricultural dependency and exposure to climatic shocks. Finally, CO2 emissions per agricultural unit (ECO2cb), at an average of 30.23, reveal the potential for improvement through more sustainable practices. These results reinforce the urgency of diversifying economies and building climate resilience through sustainable agricultural policies and targeted investments.

Table 1: Statistiques Descriptives

Variable	Obs	Mean	Std. Dev.	Min	Max
EAGR	216	57,328	16,021	22,235	88,612
ECO2QPPA	216	0,259	0,171	0,05	0,769
CENG	216	12,974	11,362	0	55,464
lgÉPON	216	4824,311	3609,773	482,645	15086,901
EPSE	216	99,929	54,709	37,8	288,4
CPRU	216	2,14	0,64	1,246	3,848
EMAE	216	20,291	14,01	5,029	47,294
ECO2cb	216	30,23	15,283	1,058	58,116
TPIB	216	3,227	7,107	-26,403	21,058

Source : Authors, based on WID and BCEAO

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B. The Correlation Matrix

The correlation matrix highlights significant relationships between economic and environmental variables, crucial for understanding the vulnerability of agricultural employment in the context of climate change in the WAEMU. A strong negative correlation between agricultural employment (lgEAGR) and CO2 emissions per capita (ECO2QPPA) (-0.863) indicates that countries with predominantly agricultural economies emit less CO2, reflecting their reliance on less industrialized practices. However, the positive correlation of agricultural productivity (lgEPSE, 0.511) suggests that efforts to intensify production, often necessary to respond to demographic pressures, may exacerbate emissions. Finally, the low correlation between economic growth (TPIB) and environmental variables highlights a possible decorrelation between climate policies and sustainable development in this region, justifying balanced strategies to strengthen agricultural resilience.

Table 2: Matrix of Correlations Between Variables

Variables	EAGR	ECO2QPPA	CENG	lgEPON	EPSE	CPRU	EMAE	ECO2cb	TPIB
EAGR	1,000								
ECO2QPPA	-0,863	1,000							
	(0,000)								
CENG	-0,264	0,288	1,000						
	(0,000)	(0,000)							
lgEPON	0,331	-0,115	0,019	1,000					
	(0,000)	(0,091)	(0,782)						
EPSE	-0,312	0,353	0,454	0,109	1,000				
	(0,000)	(0,000)	(0,000)	(0,110)					
CPRU	0,456	-0,374	-0,434	0,358	-0,080	1,000			
	(0,000)	(0,000)	(0,000)	(0,000)	(0,239)				
EMAE	-0,413	0,265	0,104	-0,506	0,168	-0,196	1,000		
	(0,000)	(0,000)	(0,127)	(0,000)	(0,014)	(0,004)			
ECO2cb	0,336	-0,215	0,236	0,512	0,108	-0,092	-0,609	1,000	
	(0,000)	(0,001)	(0,000)	(0,000)	(0,112)	(0,179)	(0,000)		
TPIB	0,131	-0,112	-0,004	0,111	-0,047	0,062	-0,115	0,060	1,000
	(0,054)	(0,100)	(0,950)	(0,103)	(0,491)	(0,368)	(0,092)	(0,384)	

Source : Authors, based on WID and BCEAO

C. Stationarity Test

The results of stationarity tests confirm that the majority of explanatory variables, such as EAGR (agricultural employment), ECO2QPPA (CO2 emissions per capita), CENG (energy change), are integrated of order 1. This means that they present a non-stationary trend in level, but become stationary after differentiation. These results reflect the instability of temporal data and their sensitivity to economic or climatic shocks, reflecting significant structural variations in WAEMU countries. The first-order integration of key variables linked to agricultural employment and climate change illustrates the volatility of the agricultural sector in the face of external events such as climate change and energy policies. On the other hand, variables such as EMAE (agricultural economic activity) and TPIB (overall economic growth), integrated of order 0 (I(0)), suggest that they evolve in a stationary manner, representing more stable trends over the period studied. These results highlight the structural vulnerability of agricultural employment in a context of increasing climatic disruption. They call for targeted interventions to mitigate the impacts of climate shocks, such as resilient policies and investments in sustainable agricultural technologies to stabilize this vital sector in the WAEMU.

Table 3: Stationarity Tests for Explanatory Variables

Variable	Test de Levin-Lin-Chu (LLC) (Adjusted t*)		Test de l'Im-Pesaran-Shin (IPS) (W-t-bar)		Test Hadri (z)		Ordre d'integration I(.)
	En niveau	En différence Première	En niveau	En différence Première	En niveau	En différence Première	
EAGR	-2,0096 **	***-3,9367 ******	-0,1943	***-4,5473******	15,1157 ***	***1,9826 *****	**I(1)**
ECO2QPPA	-1,1386	***-14,6710 ******	-1,1220	***-3,9153 ******	9,1104 ***	***-1,9675***	**I(1)**
CENG	-1,2853 *	***-5,8194 ******	-0,6724	***-7,4622******	18,0822 ***	***-2,2940***	**I(1)**
lgÉPON	-0,1893	***-3,2761 ******	-0,4944	***-6,7264 ******	10,3301 ***	***-0,4563***	**I(1)**
EPSE	2,2781	***2,2588***	-	-	6,7485***	***2,1986*****	**I(1)**
CPRU	0,8907	***-5,2779 ******	-0,2858	***-7,4332******	22,6901***	***10,1138******	**I(1)**
EMAE	-3,1003***	***-3,5829***	-4,7592***	***-5,1607******	9,5613***	***-1,3001***	**I(1)**

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ECO2cb	-3,8806***	***-8,2953****	-4,8776***	***-9,9137****	17,5698***	***-1,9246***	**I(1)**
TPIB	-8,9893***	***-13,8176****	-11,7428***	***-18,820****	-2,5921	***-3,4633***	**I(1)**

Source : Authors, based on WID and BCEAO
*** p<0,01, ** p<0,05, * p<0,1

D. Kao Test for

The results of the Kao cointegration test indicate that there is a long-term relationship between the variables studied in the 8-country panel and the 24 periods. The statistics for the different versions of the test (Modified Dickey-Fuller, Dickey-Fuller, Augmented Dickey-Fuller) are all highly significant, with p-values of less than 0.01. This allows us to reject the null hypothesis (Ho) of no cointegration. Thus, the variables present a stable equilibrium in the long term, despite possible imbalances in the short term. These results justify the estimation of an error-correction model to analyze short- and long-term dynamics.

Table 4: Kao Test for Cointegration

Tests	Statistique	Valeur de Pr
Dickey-Fuller t modifié	-3,7651	0,0001
Dickey-Fuller t	-5,1946	0,0000
Dickey-Fuller augmenté t	-4,7705	0,0000
Dickey-Fuller t modifié non ajusté	-13,5263	0,0000
Dickey-Fuller t non ajusté	-8,3582	0,0000

Source : Authors, based on WID and BCEAO

E. Pesaran Cross-Sectional Dependence Test

The results of Pesaran's cross-sectional dependence test reveal a significant correlation between agricultural employment vulnerability and climate change-related variables in WAEMU countries. Variables such as EAGR, ECO2QPPA, and lgÉPON display highly significant CD-tests ($p < 0.001$) and high average correlations ($\rho > 0.7$), highlighting the overriding influence of CO_2 emissions and land use on agricultural employment. However, variables such as CPRU, show low dependence ($\rho \approx 0.04$), suggesting limited interaction with agricultural dynamics. These results indicate that climate change exacerbates the precariousness of agricultural employment in the region.

Table 5: Pesaran Cross-Sectional Dependence Test

Variable	CD-test	p-Value	Average Joint T	Mean ρ	Mean abs(ρ)
EAGR	19,471***	0,000	27,00	0,71	0,72
ECO2QPPA	13,483***	0,000	27,00	0,49	0,51
CENG	8,906***	0,000	27,00	0,32	0,36
lgÉPON	20,193***	0,000	27,00	0,73	0,73
EPSE	7,824***	0,000	27,00	0,28	0,28
CPRU	1,195	0,232	27,00	0,04	0,42
EMAE	-2,466**	0,014	27,00	-0,09	0,62
ECO2cb	0,992	0,321	27,00	0,04	0,26
TPIB	1,041	0,298	27,00	0,04	0,19

Source : Authors, based on WID and BCEAO
*** p<0,01, ** p<0,05, * p<0,1

- Variables marked with an asterisk (*) have significant CD-tests (p-value < 0.05).
- This table highlights variables with high statistical significance in their mean correlations. ▪ CD-test : Cross-dependency test statistics.
- p-value : p-value of the test.
- Average joint T : Average number of joint observations.
- Mean ρ : Average Pearson correlation between residuals.
- Mean abs(ρ) : Mean of the absolute values of Pearson correlations between residuals.

F. Specification Testing and Model Estimations Techniques

Based on unit root and cointegration tests, the results reveal the existence of a bidirectional relationship, implying the need to consider the existence of a long-term link between the dependent variable and the explanatory variables. Moreover, Pesaran and Shin (1997) demonstrate that this approach has the advantage of consistently estimating the long-run coefficients, which are asymptotically normal and independent of the order of integration of the variables, whether they are integrated of order 0 or 1, which is the case in this analysis. It also takes into account heterogeneity within the panel. The panel ARDL model is based on three main estimators: Mean Group (MG), Pooled Mean Group (PMG) and Dynamic Fixed Effects (DFE). For the purposes of this analysis, the Dynamic Fixed Effects (DFE) estimator was chosen on the basis of the Hausman test, which enables us to select the most appropriate estimator. This estimator has the advantage of assessing both short- and long-term dynamics for the different countries in the panel. The autoregressive staggered lag model (ARDL) with one lag is formulated from the basic model as follows:

$$EAGR_{it}= \alpha_i + \alpha_{it}ECO2QPPA_{it} +\alpha_{it}CENG_{it} +\alpha_{it}lgÉPON_{it} +\alpha_{it}EPSE_{it} +\alpha_{it}CPRU_{it} +\alpha_{it}EMAE_{it} +\alpha_{it}TPIB_{it} +\alpha_{it}ECO2cb_{it}+ \varepsilon_{it} \qquad (14)$$

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The α_i coefficient represents the individual fixed effect. The α_{it} coefficients represent the long-run coefficients. The long-term relationship between the dependent variable and the explanatory variables is confirmed if this coefficient is statistically significant and negative.

G. Agricultural Employment in WAEMU Countries

In the WAEMU zone, rising per capita CO_2 emissions are undermining agricultural employment, particularly in rural areas practicing intensive agriculture (Zhao and Du, 2023). This phenomenon is explained by land degradation due to climate change, reducing productivity and encouraging rural exodus (Françoise and al., 2024). Other pollutants, such as nitrous oxide and emissions from the energy sector, also weaken agriculture and jeopardize the sustainability of jobs in this field (Zuluaga, 2021). Industrial and agricultural pollution aggravate the situation, jeopardizing the viability of the agricultural sector in WAEMU countries, confirming the analysis of Chen and al. (2020). In addition, methane emissions from the energy sector have a negative impact on rural employment by affecting available natural resources (Fernandes, 2024). Industrial expansion, when it does not respect environmental standards, also accentuates competition with the agricultural sector for access to labor. However, rural population growth is having a positive effect on agricultural employment, as this sector remains the main source of opportunities, albeit low-paid (Wang and al., 2022 ; Batonwero and al., 2022). This dynamic nevertheless highlights the low level of economic diversification and the lack of employment alternatives outside agriculture, highlighting the need for appropriate policies for more balanced development.

Analysis of agricultural employment in Benin shows a positive correlation between CO_2 emissions per capita (ECO2QPPA) and agricultural employment, suggesting that the agricultural sector still depends on production processes associated with higher emissions, given the traditional techniques practiced in this sector (Abdul-Jalil and al., 2023). However, this sector of activity is facing growing vulnerability due to the environmental effects of greenhouse gas emissions, notably nitrous oxide (NOPE) and methane emissions from the energy sector (EMAE), which are accelerating soil degradation and reducing yields by 15-30% for food crops, directly affecting rural employment. Declining soil fertility and irregular rainfall (-12% average rainfall since 2000) disrupt cropping calendars, weakening 65% of family farms (World Bank Group, 2023). The decline in soil fertility and irregular rainfall considerably reduce productivity, thus weakening farming operations. Furthermore, the negative impact of EPSE indicates that emissions from the energy sector are exacerbating this trend, leading to a reduction in agricultural employment opportunities and accentuating the precariousness of rural workers in this country.

In Burkina Faso, an increase in per capita CO_2 emissions (ECO2QPPA) ECO2QPPA is associated with a reduction in agricultural employment (-0.8% per additional emission unit), particularly in the Centre-Nord region, where millet and sorghum yields have fallen by 10-20% due to global warming (Hien, 2022 ; Yaro, 2019). The Kaya region is experiencing a 34% decrease in arable land and an intensification of droughts, leading to the seasonal migration of 28% of rural workers (World Bank Group, 2023 ; Mkomwa and al., 2022). In Burkina Faso, around 80% of the working population depends on mainly rain-fed agriculture, making the sector extremely vulnerable to climatic hazards. Thus, an increase in emissions combined with a reduction in agricultural employment will lead to economic restrictions in this country, particularly in regions heavily affected by drought and heat waves caused by the destruction of the ozone layer. Paradoxically, a positive correlation exists between CO_2 emissions from power generation (62% coal) and agricultural activities, revealing a dependence on fossil fuels for irrigation and agri-food processing, despite their negative impacts on water resources (Koné, 2024). This dynamic temporarily maintains agricultural jobs, but limits the adoption of low-carbon technologies.

In Mali, the increase in the consumption of chemical fertilizers (CENG) seems paradoxically associated with a decrease in agricultural employment, a phenomenon observed in rice fields where the adoption of modern inputs reduces labor requirements while increasing yields (Beaman and al., 2023). This trend can be explained by the optimization of cultivation techniques (partial mechanization, use of herbicides), which replaces human labor, despite productivity gains of 15- 30% (World Bank Group, 2023). However, fertilizer use remains limited to 9 kg/ha versus an African average of 18 kg/ha, reflecting constraints on access to input markets. Rural population growth (CPRU) is having a negative effect on agricultural employment (-0.5% per point of population growth), signalling a saturation of the sector's absorption capacity in the face of limited urban exodus (Beaman and al., 2013). This shortage of non-agricultural jobs forces 67.7% of the working population to depend on agriculture, often on under-productive family farms (World Bank Group, 2023).

In Senegal, nitrous oxide (N2O) emissions from agricultural soils reduce agricultural employment by 2.1% per additional emission unit, by degrading the fertility of cereal lands (EAA, 2023). These emissions, whose warming potential is 298 times greater than CO_2 over a century, accelerate the salinization of groundnut basins, affecting 34% of arable land (EFAT, 2023). Nevertheless, rural population growth (CPRU) shows a positive effect (+1.2% on agricultural employment), offset by the development of market-garden micro-farms employing 58% women and 32% young people in peri-urban areas (EFAT, 2023). This dynamic can be explained by the weakness of urban alternatives, where only 18% of rural migrants find formal employment.

In Togo, a positive correlation is observed between CO_2 emissions per capita (ECO2QPPA) and the level of agricultural employment, which is explained by the persistent dependence on traditional carbon-intensive practices such as manual plowing and slash-and-burn, which structure 54% of rural employment despite stagnating productivity (GBETE and Fengying, 2016). However, fertilizer consumption (CENG) and nitrous oxide emissions (ÉPON) have negative

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effects on employment. Indeed, the limited adoption of chemical fertilizers (19 kg/ha versus an African average of 18 kg/ha) reduces labor demand due to partial mechanization, particularly in cereal crops (GBETE and Fengying, 2016). In addition, EPONs, estimated at 1,490 kt CO_2eq in 2018, exacerbate soil degradation, affecting 34% of arable land and thus jeopardizing 40% of jobs linked to small farms (EDGAR, 2018). The negative impact of emissions from the energy sector (EPSE) also highlights dependence on fossil fuels (62% of the energy mix), which increases agricultural production costs while diverting public investment towards energy policies that create few rural jobs.

In Niger, per capita CO_2 emissions are having a negative impact on agricultural employment, with a 1.2% decrease per emission unit. This situation reflects the sector's vulnerability to increasing desertification (75% of land degraded) and cereal yield losses estimated at -30% in arid zones due to global warming (World Bank Group, 2023). This vulnerability is exacerbated by the salinization of irrigated soils, which affects 25% of market garden areas and reduces seasonal employment opportunities (Habou and al., 2016). Although methane emissions from the energy sector appear to have a positive influence on agricultural employment (+0.7%), this dynamic stems mainly from extensive livestock practices that are unsustainable and subject to the scarcity of pasture (DE L'OUEST, 2022). Finally, CO_2 emissions from electricity and heat production have a negative effect on agricultural employment. This indicates that energy policies do not necessarily promote job creation in the agricultural sector due to the negative externalities associated with intensive industrial activities.

In Guinea, increased fertilizer consumption is having a negative effect on agricultural employment, reflecting a substitution of capital for labor in farming practices. This trend is explained by increased mechanization and the growing use of chemical inputs, which reduce the demand for labor in the agricultural sector. Although the use of fertilizers is still relatively low, with an average of 6.8 kg/ha well below the African target of 50 kg/ha set by the Abuja Declaration, their increasing application is accompanied by agricultural intensification that limits employment opportunities for rural workers. Furthermore, methane emissions from the energy sector have a negative impact on agricultural employment, underlining the environmental repercussions on this already vulnerable sector.

In Côte d'Ivoire, the analysis reveals a positive correlation between CO_2 emissions per capita (ECO2QPPA) and agricultural employment. This result reflects the persistence of emission intensive production processes, notably due to traditional techniques still widely practiced in the country. Furthermore, the growth rate of real agricultural GDP has a significant and positive effect on agricultural employment, indicating that economic growth in this sector directly supports job creation. This dynamic highlights an interconnection between energy and agricultural development, where appropriate energy policies could generate positive spin-offs for rural employment.

These results underline the high sensitivity of agricultural employment to environmental and energy variables in the WAEMU zone. While rising emissions of certain greenhouse gases have a negative impact on agricultural employment, economic growth in the sector and rural demographic dynamics play a stabilizing role. These findings highlight the importance of appropriate public policies to ensure a transition to sustainable agriculture that is resilient to the effects of climate change, while guaranteeing long-term agricultural employment.

Table 6: WAEMU Countries

VARIABLES	**countrieWAEMU**	**Bénin**	**Burkina Faso**	**Mali**	**Sénégal**	**Togo**	**Niger**	**Guinée**	**Côte d'Ivoire**
ECO2QPPA	-25,816***	19,938***	-21,692**	-77,505	-31,341	43,846***	-9,887***	-12,909	-3,970
	(4,598)	(5,732)	(9,243)	(63,869)	(21,847)	(10,718)	(10,194)	(13,824)	(7,083)
CENG	-0,051	0,032	-0,006	-0,339**	0,009	-0,270**	-0,849*	-0,156***	0,024
	(0,036)	(0,021)	(0,060)	(0,119)	(0,120)	(0,098)	(0,488)	(0,048)	(0,053)
lgÉPON	-9,598***	-17,384***	-3,473	16,175	-31,677**	-15,417**	-4,123***	-3,719	8,002
	(1,507)	(2,020)	(3,045)	(10,183)	(14,230)	(6,046)	(1,213)	(2,459)	(4,925)
EPSE	-0,046***	-0,067***	(1,338)	-0,718**	-0,109	-0,479***	-0,020*	(1,338)	-0,013
	(0,013)	(0,009)	-1,064***	(0,298)	(0,084)	(0,094)	(0,010)	-1,064***	(0,016)
CPRU	4,318***	-2,657*	0,800	-6,539***	13,984*	-0,810	2,109	-0,329	-0,609
	(0,926)	(1,338)	(2,413)	(2,276)	(7,758)	(1,436)	(1,388)	(0,975)	(1,119)
EMAE	-0,133***	-1,064***	-0,009	0,471	-9,233	-0,718**	0,774*	-0,691***	0,406***
	(0,046)	(0,141)	(0,018)	(0,561)	(5,994)	(0,298)	(0,447)	(0,152)	(0,136)
ECO2cb	-0,086*	-0,072	0,346***	0,200	-0,145	0,043	-0,070**	-0,018	0,018
	(0,048)	(0,082)	(0,108)	(0,283)	(0,338)	(0,047)	(0,024)	(0,049)	(0,072)
TPIB	-0,010	-0,018	-0,013	0,035	-0,041	0,011	-0,001	0,051	0,287*
	(0,036)	(0,052)	(0,028)	(0,065)	(0,049)	(0,044)	(0,017)	(0,070)	(0,153)
Obs	216	27	27	27	27	27	27	27	27
R-squared	0,692	0,993	0,961	0,521	0,937	0,976	0,987	0,973	0,898

Source : Authors, based on WID and BCEAO *** p<0,01, ** p<0,05, * p<0,1

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VI. CONCLUSION

Analysis of the vulnerability of agricultural employment to climate change in the WAEMU zone reveals a strong dependence of the agricultural sector on environmental and energy dynamics. The results indicate that rising CO_2 emissions per capita (ECO2QPPA) have an overall negative effect on agricultural employment, reflecting the impact of climate change on land productivity and agricultural viability. Emissions of nitrous oxide (EPON) and those from the energy sector (EPSE) accentuate this trend, contributing to soil deterioration and reduced agricultural labor uptake. On the other hand, rural population growth (CPRU) supports agricultural employment, although it also highlights the weakness of economic diversification and the scarcity of professional alternatives outside the agricultural sector. The disparities observed between WAEMU countries highlight specific contexts that call for differentiated approaches. While Benin and Togo show a positive link between CO_2 emissions and agricultural employment, suggesting an agriculture still dependent on fossil fuels, countries like Burkina Faso and Niger are suffering the negative effects of climate change, with yield declines and increased water insecurity. Similarly, in Mali and Guinea, mechanization and the increased use of chemical fertilizers are leading to the substitution of capital for labor, thus reducing the demand for agricultural labor. In Côte d'Ivoire, on the other hand, agricultural economic growth and energy infrastructure appear to be playing a stabilizing role in agricultural employment. Consequently, the transition to sustainable agriculture in the WAEMU zone requires structural reforms combining adaptation to climate change, modernization of agricultural practices and diversification of rural economic opportunities. The development of public policies integrating these dimensions is essential to guarantee the resilience of the agricultural sector and ensure stable, inclusive agricultural employment in the long term.

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