ESJ Social Sciences | Peer-reviewed

# Effect of the Energy Transition on Food Security: The Role of the Female Agricultural Workforce in WAEMU Countries

***Kamalan Angbonon Eugene***
***Kadjo Assande Pierre***
Department of Economics and Management,
Alassane Ouattara University, Bouaké, Côte d'Ivoire
***Kouame Kouakou Romaric***
Department of Economics and Management,
Jean Lorougnon Guédé University, Daloa, Côte d'Ivoire

Doi:10.19044/esj.2025.v21n34p186

Submitted: 07 November 2025
Accepted: 27 December 2025
Published: 31 December 2025



*Cite As:*
Kamalan, A.E., Kadjo, A.P. & Kouame, K.R. (2025). *Effect of the Energy Transition on Food Security: The Role of the Female Agricultural Workforce in WAEMU Countries*. European Scientific Journal, ESJ, 21 (34), 186. https://doi.org/10.19044/esj.2025.v21n34p186

## Abstract

This study analyses the role of women in the relationship between the energy transition and food security in the 8 WAEMU countries (1996-2022). The use of an ARDL model shows that the energy transition significantly and symmetrically improves food security in the short term, but has a negative and asymmetric effect in the long term. The interaction between the energy transition and the female agricultural workforce has a positive effect in the long term, but is neutral in the short term. We recommend maximising short-term benefits and actively involving women in agriculture to improve long-term food security.

**Keywords:** Energy transition, female agricultural labour, Food security, WAEMU, ARDL

## Introduction

Food security remains a major challenge for economic and social development in developing countries. Despite progress in recent decades, a large proportion of the population still has limited access to sufficient, healthy and nutritious food (FAO, 2023). Between 2000 and 2010, the situation

 ISSN: 1857-7881 (Print) e - ISSN 1857-7431

improved. However, hunger worsened significantly after this period. The deterioration was particularly marked between 2019 and 2022 (FAO, 2023). In 2022, approximately 282 million people in Africa were undernourished. This represents an increase of 57 million people since the start of the COVID-19 pandemic. More than two-thirds of the populations of Central, East and West Africa face moderate or severe food insecurity (FAO, 2023). A total of 868 million people in Africa were affected in 2022. Food security is defined as physical and economic access to sufficient, safe and nutritious food. It enables people to lead active and healthy lives (FAO, 2002). However, food security can be disrupted by poorly managed climate change. Temperature variations, droughts and extreme weather events reduce agricultural yields and the availability of water and fertile soil (De Moraes Sá et al., 2017). Increased carbon dioxide ($CO_2$) levels can reduce agricultural yields and the nutritional value of crops. These fluctuations require a systemic transition of socio-economic systems in order to ensure sustainable food security (Wheeler & Von Braun, 2013).

According to a study by Agbokpanzo et al. (2023), WAEMU countries rely heavily on fossil fuels and biomass to meet their energy needs. However, a transition to clean and renewable energy sources is crucial in order to reduce greenhouse gas emissions and mitigate the effects of climate change.

In the WAEMU, climate variability, land degradation, rural poverty and low agricultural productivity exacerbate food insecurity and gender inequalities. However, women still face inequalities in access to land, credit, technology, training and energy services. Gender equality is therefore essential to eliminating hunger, malnutrition and poverty (FAO, 2021). Indeed, the inclusive adoption of clean energy technologies can reduce the drudgery of women's agricultural work. It can also increase productivity and enhance food security. Access to modern energy technologies improves women's incomes and participation in agricultural value chains (Sertyesilisik, 2023). However, women face obstacles such as unequal access to land, credit, decision-making and agricultural technologies (UNDP Report, 2014). In addition, rural women face gender-based inequalities that hinder their potential economic contribution and prevent them from fully benefiting from their work.

With a view to developing fair and effective environmental policies, this study analyses the role of women in the link between energy transition and food security.

The WAEMU countries face a real challenge in terms of food security, as out of 113 countries, the WAEMU zone ranks 91st with an index of 47. The first group includes Mali, Senegal and Burkina Faso. They rank 85th, 86th and 89th respectively. Their average food security index is 48.8, 48.4 and 47.5. A second group includes Benin, Côte d'Ivoire, Niger and Togo. They rank 91st,

 ISSN: 1857-7881 (Print) e - ISSN 1857-7431

95th, 97th and 98th respectively. Their average food security indices are 44.8, 48.4, 48 and 46.3 (FAO, 2023). The energy transition can reduce food security inequalities by avoiding a resource-intensive model (Kline et al., 2017).

Furthermore, a "just energy transition" protects workers' livelihoods, safeguards the future of communities, and ensures a low-carbon economy. This requires dialogue between employees, trade unions, government, employers, civil society, and communities (Evans & Phelan, 2016; Galgóczi, 2020). The energy transition emphasises the decentralisation of systems, the importance of location and the needs of marginalised communities (O'Neill et al., 2018; Heffron, 2021). Furthermore, a just energy transition aims for environmental integrity, economic sustainability, well-being and social resilience, supported by strong democratic governance. It thus facilitates the mapping of the energy transition to achieve outcomes aligned with the economic and social development of the communities and regions concerned. Gender equality is a matter of social justice and human development. It influences food security and participation in the energy transition (Sen, 1999; Ericksen, 2008). This equality plays a crucial role in the distribution of food resources and access to food (Ingram, 2011). Including women in the management of domestic energy resources promotes sustainable and inclusive energy solutions (Clancy et al., 2011). Renewable energy, on the other hand, can reduce dependence on fossil fuels and energy costs for farmers (FAO, 2017).

On the other hand, equitable access to resources for women can significantly increase agricultural production (Quisumbing and Pandolfelli, 2010). However, bioenergy production can compete with food production, leading to higher prices and food insecurity (Tilman et al., 2009). New energy technologies risk exacerbating inequalities if they remain inaccessible to vulnerable populations, such as smallholder farmers (Van der Horst & Vermeylen, 2011). Thus, inequalities in access to natural and financial resources can limit the benefits of the energy transition and threaten food security.

Thus, to be effective, policies must reduce inequalities and rely on inclusive regulatory frameworks for the governance of energy transition and food security (Clapp & Fuchs, 2009). Hlahla (2022) analyses the water-energy-land-food security (WELF) nexus in sub-Saharan Africa, highlighting gender inequalities. He shows that WELF policies and projects are often gender-blind, limiting their effectiveness and sometimes reinforcing inequalities. Women's lack of land rights, their dependence on traditional energy sources and their vulnerability to climate change compromise food security and the sustainability of productive systems. These frameworks are also criticised for favouring businesses and political elites at the expense of local communities (Scoones, 2015).

 ISSN: 1857-7881 (Print) e - ISSN 1857-7431

Furthermore, some renewable technologies can harm the environment, such as hydroelectric dams, which displace populations and disrupt ecosystems (Ansar et al., 2014). Feminist economics highlights the undervaluation of women's unpaid work and advocates for a fair redistribution of domestic tasks to strengthen food security (Folbre, 2021). The intersectional approach helps to understand how different forms of discrimination exacerbate food inequalities (Crenshaw, 2019). Globalised food systems concentrate production and distribution among a few large companies, increasing food insecurity. This reinforces the need for local and sustainable food systems that take into account the needs of communities, particularly women (McMichael, 2020).

Food sovereignty and agroecology emphasise the right of peoples to control their food systems and practise sustainable agriculture (Pimbert, 2018). Rural women face barriers to accessing essential resources, limiting their production and access to nutritious food (Doss, 2018). Traditional gender roles confine them to domestic and care tasks, reducing their economic and agricultural participation, which affects their food security and that of their families (FAO, 2020).

Furthermore, women are particularly vulnerable to climate change due to their dependence on natural resources and their role in household management (Sertyesilisik, 2023). The under-representation of women in decision-making limits their influence on policies that affect their food security (Cornwall, 2016). It is therefore necessary to radically reform agricultural and food policies to promote gender equality and strengthen food security (Quisumbing & Meinzen-Dick, 2020).

## Data

The aim of this article is to analyse how complementarity between the energy transition and women's employment in agriculture can strengthen food security in WAEMU countries.

Annual data covering eight WAEMU countries (Benin, Burkina Faso, Côte d'Ivoire, Guinea-Bissau, Mali, Niger, Senegal and Togo) from 1996 to 2022 were used in the analysis. The summary of the variables in this study is presented in Table 1 below. *The variable of food security is a flexible and diverse concept with various definitions. According to the FAO (2023), food security is a condition in which everyone has physical, social and financial access at all times to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life.* The "pillars" associated with food security are availability, utilisation, accessibility and stability (Grainger, 2016; Aliaga and Chaves Dos Santo, 2014). In terms of (local) food production and distribution, with an emphasis on supply, food accessibility refers to the ease of access to nutritional sources. The ability of a

 ISSN: 1857-7881 (Print) e - ISSN 1857-7431

household or individual to obtain readily available food is called food access. Since food security exists when all individuals have physical, economic and social access to sufficient, safe and nutritious food at all times, we use the food production index as a measure.

The food production index covers food crops that are considered edible and contain nutrients. Our variables of interest are, on the one hand, the energy transition, which is measured by the consumption of renewable energy (ERN) as a percentage of total energy, according to studies by Najm and Matsumoto (2020), Zhuang et al, (2022) and Pons and Tanguy (2021). Energy transition can be effective in increasing the level of food supply. This implies that traditional energies lead to lower productivity due to their massive costs, whereas in the case of renewable energies, the total cost of production may decrease and lead to a further increase in the level of food supply. The energy transition can also help reduce inequalities in food security that could influence existing food security systems by avoiding the resource-intensive model (Kline et al., 2016). On the other hand, female agricultural employment, which reflects the number of women employed in the agricultural sector as a percentage of total female employment. Agricultural employment is crucial for food security, as women in most developing countries are responsible for the nutrition and well-being of their families, which reinforces their role in food security.

**Table 1:** Study variables

| Variables | Definition | Sources |
|---|---|---|
| ***IPA*** | Food production index | World Development Indicator (WDI, 2024) |
| ***ERN*** | Renewable energy consumption as a percentage of total energy consumption | World Development Indicator (WDI, 2024) |
| ***EAFEM*** | Women in agricultural employment | FAO stat (2024) |
| ***EDUF*** | Female primary school enrolment rate | ILO Stat (2024) |
| ***GDP*** | GDP per capita | World Development Indicator (WDI, 2024) |
| ***STAB*** | Political stability, absence of violence | Worldwide Governance Indicator (WGI, 2024) |
| ***PRE*** | Precipitation in minutes per year | Energy Statitics Data (2024) |
| ***CO2*** | CO2 consumption as a percentage of GDP | Energy Statitics Data (2024) |
| ***ARABL*** | Arable land | FAO stat (2024) |
| ***AOI*** | Agricultural orientation index of public expenditure. | FAO stat (2024) |
| ***MOA*** | Agricultural mechanisation. Use of tractors and machinery. | FAO stat (2024) |
| ***POP*** | Population growth rate | World Development Indicator (WDI, 2024) |

Source: The authors

 ISSN: 1857-7881 (Print) e - ISSN 1857-7431

Similarly, women's employment in agriculture is essential to ensuring sustainable food security because of their contribution to food production, crop diversification, access to resources and the promotion of sustainable agricultural practices. Women often have valuable knowledge of sustainable agricultural practices and natural resource management. Their involvement in decision-making regarding land and resource use can contribute to more sustainable agriculture, thereby preserving long-term food security. For control variables, we use macroeconomic variables such as GDP per capita to measure per capita income. We also use energy variables such as precipitation in mm/year and $CO_2$ consumption. Institutional variables such as the agricultural orientation index of public expenditure are used to measure progress in agricultural financing. This is an index that allows for an accurate assessment of government commitment to agriculture, and economic stability is used to measure the absence of violence. In addition, variables related to population, education and agriculture such as population growth rate, female education, use of machinery and tractors, and arable land are used. A summary of the variables used is presented in Table 1 above.

## Methodology

The aim here is to describe the basic theoretical model, specific to the estimation technique.

## Model used

In the neoclassical production function, the sources of production are the accumulation of production factors and the improvement of total factor productivity. The starting point for our modelling is the Cobb-Douglass production function defined as follows :

$$Y = AK^{\beta}L^{\alpha} \tag{1}$$

where Y represents production output, A represents total productivity, K represents capital, and L represents labour inputs, while β and α are the coefficients of capital (K) and labour (L) production. However, Zhang et al. (2022) and Zakari et al. (2022) argued that energy has become a factor of production because it drives economic development. Thus, equation 1 above becomes :

$$Y = AK^{\beta}L^{\alpha}E^{\sigma} \tag{2}$$

Applying the logarithm to equation 2, we obtain the following equation 3 :

$$y = a + \beta k + \alpha l + \sigma e \tag{3}$$

Where y is the logarithm of output, a is the logarithm of total factor productivity, k is the logarithm of capital, l is the logarithm of labour, and e is the logarithm of energy. Then $\beta$, $\alpha\ et\ \sigma$ are the elasticities of capital, labour, and energy, respectively.

Based on studies by Ogbolumani and Nwulu (2022); Fetanat et al. (2021); Lu et al. (2021); Zakari et al. (2022) and Agbokpanzo et al, (2023), our objective is to analyse the role of women in the relationship between energy transition and food security. We specify our model as follows :

Model 1: No interaction

$$lnIPA_{it} = \beta_0 + \beta_1 lnERN_{it} + \beta_2 lnEDUF_{it} + \beta_3 lnPRE_{it} + \beta_4 lnGDP_{it} + \beta_5 POP_{it} + \beta_6 CO_{2\,it} + \beta_7 lnARABL_{it} + \beta_8 lnMOA_{it} + \beta_9 lnSTAB_{it} + \beta_{10} AOI_{it} + \varepsilon_{it} \quad (4)$$

Model 2: With interaction

$$lnIPA_{it} = \beta_0 + \beta_1 lnERN \times EAFEM_{it} + \beta_2 lnEDUF_{it} + \beta_3 lnPRE_{it} + \beta_4 lnGDP_{it} + \beta_5 POP_{it} + \beta_6 CO_{2\,it} + \beta_7 lnARABL_{it} + \beta_8 lnMOA_{it} + \beta_9 lnSTAB_{it} + \beta_{10} AOI_{it} + \varepsilon_{it} \quad (5)$$

Where IPA refers to the food production index. ERN refers to renewable energy, EDUF refers to female primary school enrolment, PRE refers to precipitation in mm/year. GDP refers to GDP per capita; POP refers to annual population growth rate. $CO_2$ refers to carbon dioxide consumption as a percentage of GDP; ARABL refers to arable land. MOA refers to training women in modern and sustainable farming practices, which is equal to the product of women's primary education and the use of machinery and tractors; STAB refers to economic stability and the absence of violence. EAFEM refers to women's employment in agriculture.

AOI, agricultural orientation index of public expenditure, and $ERNF{\times}EAFEM$ represents an interaction variable between renewable energy and female agricultural employment, which represents women's involvement in the use of sustainable practices (ERNF). $\varepsilon$ represents the error term. Furthermore, i and t represent the individual and temporal dimension indices, respectively.

**Estimation technique**

Dynamic panel models are estimated using the Generalised Method of Moments (GMM) proposed by Arellano and Bond (1991), the system-GMM estimator proposed by Arellano and Bover (1995) and Blundell and Bond (1998), and represented in ARDL form as proposed by Pesaran et al. (1999). The first two models require that the data include a large number of countries relative to the period (Roodman, 2009). These conditions appear to be violated

ISSN: 1857-7881 (Print) e - ISSN 1857-7431

by this study due to the very small number of countries relative to the period. Furthermore, these estimation procedures are likely to produce non-convergent and misleading long-run coefficients unless the slope coefficients are indeed identical (Pesaran and Shin, 1999). Based on Pesaran et al. (1999), we can use an ARDL (p,q) representation to model a homogeneous dynamic panel in the form of an error correction model.

In an Auto Regressive Distributive Lags (ARDL) model, estimates are made using the Pooled Mean Group (PMG), Mean Group (MG) and Dynamic Fixed Effects (DFE) methods proposed by Pesaran et al. (2001). The advantage of the PMG method is that it considers the combination of pooling and averaging coefficients. This estimator allows a distinction to be made between short-term and long-term dynamics and takes into account the heterogeneity of countries. The PMG estimator also resolves problems of endogeneity and heterogeneity in a dynamic specification. The MG estimator considers the heterogeneity of long-term coefficients by taking their average. Like the PMG estimator, the DFE estimator restricts the vector coefficients to be equal across all panels. In the estimation process, the study favours the Pooled Mean Group (PMG) estimator given its ability to take into account endogeneity and heterogeneity issues in dynamic models on the one hand, and the fact that it considers the combination of pooling and the mean of the coefficients on the other. However, these conditions can be satisfied by including ARDL lags (p,q) for the dependent (p) and independent (q) variables as error corrections as follows :

$$\Delta IPA_{i,t} = \theta_{1j} ECT_{1i,t-1} + \sum_{j=1}^{q_1} \lambda_{ij} \Delta IPA_{i,t-1} + \sum_{j=1}^{q_1} \gamma_{ij} \Delta X_{i,t-1} + \sum_{j=1}^{q_1} \delta_{ij} Z_{i,t-1} + \varepsilon_{i,t} \tag{6}$$

Where $\theta_i ECT_{i,t-1} = Y_{i,t-1} - \phi_{0i} - \phi_{1i} X_{t-1}$ is the linear error correction term for each unit, the parameter $\theta_i$ is the error correction rate of the adjustment term for each individual, which is also equivalent to $\beta_{1i}$. The parameters $\phi_{0i}$ and $\phi_{1i}$ are calculated by setting $-\frac{\beta_{0i}}{\beta_{1i}}$ and $-\frac{\beta_{2i}}{\beta_{1i}}$ respectively in each model. X and Z represent the vectors of interest and control variables respectively.

## Empirical results

Here, we will first present the results of the econometric tests, followed by the estimation results.

ISSN: 1857-7881 (Print) e - ISSN 1857-7431

## Test results

Here we perform Fisher's homogeneity tests, individual dependency tests, and unit root tests.

## Results of preliminary tests on panel data

When examining relationships in a panel data model, two potential problems must be taken into account. First, the problem of homogeneity or heterogeneity among individuals. The coefficients associated with individuals may not be homogeneous, given that countries differ in their stages of development and levels of technology. In general, the assumption of homogeneity may mask country-specific characteristics (Menyah et al., 2014). Secondly, there is the problem of cross-country dependence, which means that a shock affecting one country may also affect other countries in the model due to direct and indirect economic links between countries.

Testing homogeneity and cross-sectional dependence therefore seems to us to be an important step in a panel data model. For the problem of homogeneity between individuals, we use Fisher's test, as it allows us to see whether there is overall homogeneity between the coefficients and constants. The null hypothesis (H0) states that the panel is homogeneous. In other words, the constants and coefficients are identical. On the other hand, the alternative hypothesis (H1) postulates the presence of individual effects between the panel data. At a significance level set a priori at 5%, if Fisher's probability is greater than this threshold, there is homogeneity, so we accept H0; otherwise, we reject H0. With regard to the problem of cross-sectional dependence, the LM test (i.e. the Lagrange multiplier for cross-sectional dependence) was developed by Breusch and Pagan (1980), and Pesaran (2004) subsequently developed the LM CD cross-sectional dependence test for small panels. However, when the number of units (N) is small and the time dimension (T) is large, the LM test by Breusch and Pagan (1980) is preferred over that of Pesaran (2004). In the case of our work, N=7 and T=31, we therefore use the Breusch and Pagan test (1980). This test is based on the null hypothesis (H0) of inter-individual independence between cross-sectional units against the alternative hypothesis (H1) of dependence. We accept the null hypothesis if the probability is below the 5% significance threshold; otherwise, we accept the H1 hypothesis. The results of these tests are shown in Table 2 below.

 ISSN: 1857-7881 (Print) e - ISSN 1857-7431

**Table 2:** Summary of cross-sectional dependence and homogeneity tests

| Équations | Model 1: Model without interaction | | Model 2: Model with interaction | |
|---|---|---|---|---|
| Fisher's Homogeneity Test | | | | |
| | Statistics | Prob | Statistics | Prob |
| Fisher | 118.67*** | 0.0000 | 150.20*** | 0.0000 |
| Breusch-Pagan cross-sectional dependence test (1980) | | | | |
| Breusch-Pagan (1980) | 87.134*** | 0.0000 | 72.915*** | 0.0000 |

Source: Author, based on data from BCEAO (2021) and WDI (2021)

*Note: (***) represents significance at the 1% threshold. Models 1 and 2 represent the model without interaction and with interaction between the energy transition and women's agricultural employment, respectively.*

## Results on unit root tests

Studying the stationarity of a variable means testing for the presence or absence of a unit root. There are two types of unit root tests for panel data. The first category is called first-generation tests. Tests in this category are based on the assumption of cross-sectional independence of units.

The second category is called second-generation tests, which are based on the assumption of unit dependence. Given that there is inter-individual dependence, the order of integration of the series must be determined using second-generation unit root tests. For our analysis, we use Pesaran's (2007) (CDF) and Pesaran's (2003) (PESCADF) tests. The null hypothesis of these tests assumes that all series are non-stationary. The test results are shown in Table 2 below.

The second-generation unit root tests by Pesaran (2003) and Pesaran (2007) reveal that the variables precipitation (PRE), agricultural orientation index (AOI), population growth rate (POP), arable land (ARABLE), GDP per capita (GDP), female agricultural employment (EAFEM) and machine and tractor use (MOA) are stationary in level. However, the variables food production index (IPA), CO2 consumption (CO2), renewable energy (ERN) and female primary school enrolment rate (EDUF) are not stationary in level, but in first difference (see Table 2 below).

 ISSN: 1857-7881 (Print) e - ISSN 1857-7431

**Table 3:** Unit root test on study variables

| Variables | Pesaran (2007) CIPS | | Pesaran (2003) PESCADF | | Décision |
|---|---|---|---|---|---|
| | Niveau | Différence | Niveau | Différence | |
| **LIPA** | -0.935 (0.175) | -6.787*** (0.000) | -2.081 (0.175) | -4.087*** (0.000) | I(1) |
| **LERN** | 0.570 (0.716) | -3.398*** (0.000) | -1.564 (0.716) | -2.925*** (0.000) | I(1) |
| **LPRE** | -3.874*** (0.000) | - | -3.088*** (0.000) | - | I(0) |
| **AOI** | -1.418* (0.078) | - | -3.663* (0,000) | - | I(0) |
| **LSTAB** | -4.709*** (0.000) | - | -3.375*** (0.000) | - | I(0) |
| **$CO_2$** | 1.759 (0.961) | -4.552*** (0.000) | -1.157 (0.961) | -3.321*** (0.000) | I(1) |
| **POP** | -3.242*** (0.001) | - | -2.872*** (0.001) | - | I(0) |
| **LARABLE** | -1.423* (0.077) | - | -2.248*** (0.077) | - | I(0) |
| **LGDP** | -3.519*** (0.000) | - | -2.967*** (0.000) | - | I(0) |
| **LEDUF** | -1.285 (0.099) | -2.593*** (0.005) | -2.201 (0.099) | -2.649*** (0.005) | I(1) |
| **EAFEM** | -1.501* (0.067) | - | -2.275* (0.067) | - | I(0) |
| **MOA** | -6.579*** (0.000) | - | -4.016*** (0.000) | - | I(0) |

Source: Author based on data from the BCEAO database (2021) and WDI (2021)

*Note: (*) and (***) represent significance at the 1% and 10% thresholds respectively.*

## Panel cointegration test

The concept of cointegration can be defined as a systematic long-term co-movement between two or more economic variables (Yoo, 2006). However, authors such as Pedroni (1999, 2004), Kao (1999) and Westerlund (2005) have proposed cointegration tests that apply to longitudinal data. Unlike the tests developed by Pedroni and Westerlund, Kao considers the special case where the cointegration vectors are assumed to be homogeneous across individuals. In other words, these tests do not allow for heterogeneity under the alternative hypothesis. Kao (1999) also proposed tests of the null hypothesis of no cointegration: the Dickey-Fuller test and the Augmented Dickey-Fuller test. The tests developed by Pedroni (1999, 2004) and Westerlund (2005 and 2007) are only applicable to regressors with fewer than seven variables. For our analysis, we have nine regressors, so we use Kao's test (1999).With regard to Kao's test, the results of models 1 and 2 show that the probability associated with the unadjusted Dickey-Fuller t-statistic and the augmented Dickey-Fuller t-statistic is 0.0000, 0.0000 and 0.0000 respectively.

ISSN: 1857-7881 (Print) e - ISSN 1857-7431

This allows us to reject the null hypothesis of no cointegration and accept the alternative hypothesis of cointegration between the variables in the long term (see Table 4 below).

**Table 4:** Kao's cointegration test (1999)

| | Model 1 | | Model 2 | |
|---|---|---|---|---|
| Tests | Statistic | P-Value | Statistic | P-Value |
| Dickey-Fuller modifié | 1.5260 | 0.0635 | 1.1217 | 0.1310 |
| Dickey–Fuller | 1.4077 | 0.0796 | 0.4481 | 0.3270 |
| Dickey–Fuller Augmenté | 3.1074 | 0.0009 | 2.2071 | 0.0137 |
| Dickey-Fuller Modifé inadjusté | -3.9201 | 0.0000 | -6.3587 | 0.0000 |
| Dickey-Fuller Inadjusté | -2.6735 | 0.0038 | -4.3775 | 0.0000 |

Source: Authors, based on data from BCEAO (2021) and WDI (2021)

## Estimation results

Here we present the short- and long-term results of our estimates.

## Short-term results

Our short-term results show that the energy transition coefficient (LERN) is positive and statistically significant. Thus, a 1% increase in energy transition leads to a 0.6879% increase in food security. This result shows that switching from fossil fuels to renewable energy sources can have positive effects on food security. Indeed, the energy transition contributes to food security by helping to reduce $CO_2$ and other greenhouse gas emissions and limiting the impacts of climate change. A more stable climate helps protect crops, soil and water resources, creating more sustainable, resilient and equitable food systems. Furthermore, renewable technologies, such as solar pumps for irrigation, enable more efficient use of water resources, which are essential for agriculture, especially in arid or semi-arid regions.

Our findings are consistent with the conclusions of Zhuang et al. (2022) for Egypt, Morocco, Tunisia and Lebanon, and Zakari et al. (2022) for 28 African countries, for whom the energy transition is fundamental to achieving food security and eliminating hunger.

Our findings also show that rainfall, although crucial for agriculture, can have negative effects on food security when it is excessive. On the one hand, heavy rainfall can cause flooding, destroying crops, seeds and agricultural infrastructure (rural roads, storage systems, markets). This damage directly reduces agricultural production and compromises food availability, particularly for rural households dependent on subsistence farming. On the other hand, increased rainfall disrupts agricultural schedules. When rains occur intensely or at inappropriate times, they negatively affect crop growth, promote plant lodging and increase post-harvest losses. This climate instability reduces yields and increases food uncertainty.

 ISSN: 1857-7881 (Print) e - ISSN 1857-7431

Furthermore, the agricultural orientation index of public expenditure (AOI) has a negative effect on food security. On the one hand, when agricultural expenditure is mainly directed towards low-productivity projects or export crops at the expense of food crops, the impact on local food availability can be limited or even negative. On the other hand, institutional and structural constraints can limit the effectiveness of public agricultural expenditure, exacerbating food insecurity. As for economic growth, our results show that it has a positive effect on food security.

In the short term, growth promotes job creation and reduces unemployment, particularly in agricultural and non-agricultural sectors linked to the food value chain. Improved employment opportunities strengthen households' ability to cope with food shocks and smooth their consumption, thereby contributing to better food availability and accessibility.

**Table 5:** Short-term results

| | **MODEL 1: WITHOUT INTERACTION** | | | **MODEL 2: WITH INTERACTION** | | |
|---|---|---|---|---|---|---|
| **Variables** | Coefficients | Ecart-type | P-Value | Coefficients | Ecart-type | P-Value |
| **LERN** | 0.687976** | 0.310430 | 0.027 | - | - | - |
| **LERNF** | - | - | - | 0.071127 | 0.30205 | 0.814 |
| **LPRE** | -0.21270*** | 0.113019 | 0.06 | 0.145038 | 0.19603 | 0.459 |
| **AOI** | -0.498706 | 0.321073 | 0.120 | -0.59119** | 0.28107 | 0.035 |
| **LSTABP** | 0.028817 | 0.025917 | 0.266 | 0.016547 | 0.01349 | 0.220 |
| **$CO_2$** | 0.820014 | 1.14859 | 0.475 | -0.96085 | 1.2273 | 0.434 |
| **POP** | -0.173110 | 0.149865 | 0.248 | -0.10194 | 0.11349 | 0.369 |
| **LARABLE** | 1.170548 | 1.40516 | 0.405 | -0.503268 | 0.710333 | 0.479 |
| **LGDP** | 0.884169** | 0.405562 | 0.029 | 0.943734** | 0.393205 | 0.016 |
| **LMEDUF** | -0.003873 | 0.004254 | 0.363 | -0.00722*** | 0.002415 | 0.003 |
| **ECT** | -0.521242 | 0.16068 | 0.001 | -0.54501*** | 0.16086 | 0.001 |
| **Cste** | -33.58591 | 13.11588 | 0.010 | -30.8499*** | 10.18529 | 0.002 |

Source: Authors, based on data from BCEAO (2021) and WDI (2021)

*Note: (*), (**) and (***) represent significance at the 1%, 5% and 10% thresholds respectively.*

## Long-term results

Our long-term results show that energy transition has a negative effect on food security, whereas the presence of female agricultural labour has a positive effect. Indeed, a 1% increase in energy transition leads to a 0.929% decrease in food production.

This result suggests that increased competition between energy crops and food crops can cause food prices to rise, making access to food more difficult for the most vulnerable populations and exacerbating food insecurity in the long term. Our results are consistent with the study by Kim (2019). He argues that, due to increased industrial production, urbanisation and economic development, as well as the expansion of transport systems, the energy transition in developing countries is leading to a significant increase in the

 ISSN: 1857-7881 (Print) e - ISSN 1857-7431

accessibility and affordability of energy services, which in some cases may lead to a decrease in food supply.

As for our interaction variable, i.e. women's agricultural employment and energy transition, the coefficient is statistically significant and positive. This is in line with our expectations. Our results show that countries that adopt energy transition by reducing gender inequalities in agricultural employment are more likely to improve their food security. These results show that a fair and inclusive energy transition that takes into account the participation of men and women in agricultural production is essential to eradicating hunger, malnutrition and poverty and positively affecting food security. With better access to sustainable energy resources, women farmers can diversify their crops and agricultural practices.

This can strengthen the resilience of food systems to climate change and climate hazards, thereby reducing the risks of crop losses and food insecurity. Our findings are consistent with the conclusions of Hlahla (2022), who states that unequal access to resources, gender inequalities, socio-economic vulnerability and cultural norms contribute to women's vulnerability to the impacts of climate change and limit their ability to seize the opportunities it presents. Reducing women's vulnerability to the impacts of climate change in sub-Saharan Africa and improving equitable access to natural resources and their efficient use will require a transformation of gender relations and the active participation of both men and women in reducing food insecurity.

**Table 6:** Long-term results

| | **MODEL 1: WITHOUT INTERACTION** | | | **MODEL 2: WITH INTERACTION** | | |
|---|---|---|---|---|---|---|
| **Variables** | Coefficients | Ecart-type | P-Value | Coefficients | Ecart-type | P-Value |
| **LERN** | -0.92958*** | 0.16344 | 0.000 | - | - | - |
| **LERNF** | - | - | - | 0.078657** | 0.03046 | 0.010 |
| **LPRE** | 0.31119*** | 0.10590 | 0.003 | -0.31597** | 0.15423 | 0.040 |
| **AOI** | 0.12117*** | 0.0428 | 0.005 | 0.58314*** | 0.075393 | 0.000 |
| **LSTABP** | 0.02792** | 0.01186 | 0.019 | 0.004817 | 0.014832 | 0.745 |
| **$CO_2$** | -0.65338** | 0.28637 | 0.023 | -0.22750 | 0.223720 | 0.309 |
| **POP** | 0.258071*** | 0.02865 | 0.000 | 0.073292** | 0.031589 | 0.020 |
| **LARABLE** | 0.279460 | 0.349319 | 0.424 | 1.21175*** | 0.133237 | 0.000 |
| **LGDP** | -0.081025 | 0.101719 | 0.426 | 0.076352 | 0.070516 | 0.279 |
| **LMEDUF** | 0.001902 | 0.006107 | 0.755 | 0.01994*** | 0.005852 | 0.001 |

Source: Authors, based on data from BCEAO (2021) and WDI (2021)

*Note: (*) , (**) and (***) represent significance at the 1%, 5% and 10% thresholds respectively.*

 ISSN: 1857-7881 (Print) e - ISSN 1857-7431

**Table 7:** Results of the Wald test for short-term and long-term

| Variable | Short term | Long term |
|---|---|---|
| $LERN^{+} = LERN^{-}$ | 0,06 | 11,70 |
| | (0,8094) | (0,0006) |
| $LEAFEM^{+} = LEAFEM^{-}$ | 2,59 | 61,85 |
| | (0,1075) | (0,0000) |
| $LERNF^{+} = LERNF^{-}$ | 0,01 | 18,35 |
| | (0,9130) | (0,0000) |

Source: Authors

The Wald test was used to show the presence of asymmetry in our short- and long-term variables. According to Table 7 above, the results indicate that the null hypothesis of no asymmetry can be rejected in the long term. Therefore, we accept that there are asymmetric effects of renewable resources, female agricultural employment and their interaction only in the long term, but symmetric in the short term.

## Conclusion and economic policy recommendations

This study provides an in-depth analysis of the interactions between energy transition, food security and the role of women in WAEMU countries over the period 1996-2022. The use of an ARDL model across all eight WAEMU countries indicates that the energy transition, while significantly and symmetrically improving food security in the short term, generates negative and asymmetric effects in the long term. This finding suggests that, although immediate benefits may result from increased energy resources, these positive effects are likely to be reduced or reversed as long-term dynamics stabilise, possibly due to dependence on energy models that are unsustainable or ill-suited to local conditions. However, the study also highlights the crucial role of female agricultural labour in managing these transitions. The interaction between energy transition and women's participation in agriculture shows a positive long-term effect on food security, although this effect is neutral in the short term. This underscores the importance of adopting an inclusive approach that recognises women's contributions not only as beneficiaries, but also as central actors of change, particularly in the sustainable management of agricultural and energy resources. Thus, in order to maximise the benefits of the energy transition while ensuring long-term sustainable food security, it is essential to strengthen women's involvement in the agricultural sector. Public policies and private initiatives must promote women's access to sustainable energy resources, while supporting their key role in innovation and the management of agricultural practices. At the same time, energy transition management strategies that anticipate long-term effects must be put in place so as not to compromise future food security.

 ISSN: 1857-7881 (Print) e - ISSN 1857-7431

## Limitations and future research

This study uses aggregate variables for energy transition (renewable energy) and food security (food production), which prevented analysis of the specific effect of the variables comprising energy transition and food security. Future research could therefore focus on a more detailed analysis of the different components of energy transition and food security. By examining the specific effect of each variable on the relationship between energy transition and food security. And also the effects of the interactions between the components of energy transition and female agricultural labour on food security. Such approaches will provide a better understanding of the underlying mechanisms and will be useful in identifying the most critical components of the energy transition in order to optimise public investment in a more targeted manner in food security.

**Conflict of Interest:** The authors reported no conflict of interest.

**Data Availability:** All data are included in the content of the paper.

**Funding Statement:** The authors did not obtain any funding for this research.

## References:

1. Agbokpanzo, A. T., Houssou, K. P., Zogbasse, S., & Alinsato, A. S. (2023). Transition énergétique dans les pays de l'UEMOA : Quel rôle dans l'amélioration du bien-être du genre ? Revue française d'économie et de gestion, 4(5), 78–96.
2. Aliaga, M. A., & Chaves-Dos-Santos, S. M. (2014). Food and nutrition security public initiatives from a human and socioeconomic development perspective: Mapping experiences within the 1996 World Food Summit signatories. Social Science & Medicine, 104, 74–79.
3. Altieri, M. A. (2009). Agroecology, small farms, and food sovereignty. Monthly Review.
4. Ansar, A., Flyvbjerg, B., Budzier, A., & Lunn, D. (2014). Should we build more large dams? The actual costs of hydropower megaproject development. Energy Policy, 69, 43–56.
5. Arellano, M., & Bond, S. (1991). Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations. The Review of Economic Studies, 58(2), 277–297.
6. Arellano, M., & Bover, O. (1995). Another look at the instrumental variable estimation of error-components models. Journal of Econometrics, 68(1), 29–51.

7. Blundell, R., & Bond, S. (1998). Initial conditions and moment restrictions in dynamic panel data models. Journal of Econometrics, 87(1), 115–143.
8. Breusch, T. S., & Pagan, A. R. (1980). The Lagrange multiplier test and its applications to model specification in econometrics. The Review of Economic Studies, 47(1), 239–253.
9. Clancy, J., Skutsch, M., & Batchelor, S. (2011). Gender equity in access to and benefits from modern energy and improved energy technologies. World Development Report Background Paper.
10. Clapp, J., & Fuchs, D. (2009). Agrifood corporations, global governance, and sustainability: A framework for analysis. In Corporate power in global agrifood governance.
11. Cornwall, A. (2016). Women's empowerment: What works? Journal of International Development, 28(3), 342–359.
12. Crenshaw, K. (2019). 'Difference' through intersectionality. In Dalit feminist theory (pp. 139–149). Routledge India.
13. De Moraes Sá, J. C., Lal, R., Cerri, C. C., Lorenz, K., Hungria, M., & de Faccio Carvalho, P. C. (2017). Low-carbon agriculture in South America to mitigate global climate change and advance food security. Environment International, 98, 102–112.
14. Doss, C. R. (2018). Women and agricultural productivity: Reframing the issues. Development Policy Review, 36(1), 35–50.
15. Ericksen, P. J. (2008). Conceptualizing food systems for global environmental change research. Global Environmental Change.
16. Evans, G., & Phelan, L. (2016). Transition to a post-carbon society: Linking environmental justice and just transition discourses. Energy Policy, 99, 329–339.
17. FAO, FIDA, OMS, PAM, & UNICEF. (2023). L'état de la sécurité alimentaire et de la nutrition dans le monde 2023. FAO. https://doi.org/10.4060/cc6550fr
18. FAO. (2017). The future of food and agriculture: Trends and challenges. FAO.
19. FAO. (2020). La situation mondiale de l'alimentation et de l'agriculture 2020 : Relever le défi de l'eau dans l'agriculture. FAO. https://doi.org/10.4060/cb1447fr
20. FAO. (2021). Politique de la FAO sur l'égalité des sexes 2020–2030. FAO.
21. Fetanat, A., Tayebi, M., & Mofid, H. (2021). Water–energy–food security nexus based selection of energy recovery from wastewater treatment technologies. Sustainable Energy Technologies and Assessments, 43.

 ISSN: 1857-7881 (Print) e - ISSN 1857-7431

22. Folbre, N. (2021). La Revue internationale du Travail et l'égalité entre hommes et femmes. Revue internationale du Travail, 160(4), 30–39.
23. Galgóczi, B. (2020). Just transition on the ground. European Journal of Industrial Relations, 26(4), 367–382.
24. Grainger, R. (2016). Fisheries and aquaculture. In Routledge handbook of food and nutrition security (pp. 153–168).
25. Heffron, R. J. (2021). Achieving a just transition to a low-carbon economy. Palgrave Macmillan.
26. Hlahla, S. (2022). Gender perspectives of the water, energy, land, and food security nexus in sub-Saharan Africa. Frontiers in sustainable food systems, 6.1-13.
27. Ingram, J. (2011). A food systems approach to researching food security. Food Security.Kao, C. (1999). Spurious regression and residual-based tests for cointegration in panel data. Journal of Econometrics, 90(1), 1–44.
28. Kim, J. E. (2019). Sustainable energy transition in developing countries. Climate Policy, 19(1), 1–16.
29. Kline, Keith L.; Msangi, Siwa; Dale, Virginiah; Woods, Jeremy; Souza, Glaucia M.; et al. 2017. Reconciling food security and bioenergy: Priorities for action. GCB Bioenergy 9 (3): 557-576. https://doi.org/10.1111/gcbb.12366
30. Malapit, H. J., Meinzen-Dick, R. S., Quisumbing, A. R., & Zseleczky, L. (2020). Women: Transforming food systems for empowerment and equity.
31. McMichael, C. (2020). Human mobility, climate change, and health. The Lancet Planetary Health, 4(6), 217–218.
32. Menyah, K., Nazlioglu, S., & Wolde-Rufael, Y. (2014). Financial development, trade openness and economic growth in Africa. Economic Modelling, 37, 386–394.
33. Mol, A.P.J. and Spaargaren, G. (2000) Ecological Modernisation Theory in Debate: A Review. Environmental Politics, 9, 17-49. https://doi.org/10.1080/09644010008414511
34. Najm, S., & Matsumoto, K. (2020). Does renewable energy substitute LNG trade? Energy Economics, 92.
35. O'Neill, D.W., Fanning, A.L., Lamb, W.F., and Steinberger, J.K. (2018). A good life for all within planetary boundaries. Nature Sustainability 1, 88-95. doi:10.1038/s41893-018-0021-4
36. Patel, R. (2009). Food sovereignty. The Journal of Peasant Studies.
37. Pedroni, P. (2004). Panel cointegration. Econometric Theory, 20(3), 597–625.
38. Pedroni, P. (1999). Critical Values for Cointegration Tests in Heterogeneous Panels with Multiple Regressors. Oxford Bulletin of

 ISSN: 1857-7881 (Print) e - ISSN 1857-7431

Economics and Statistics, 61, 653-670. https://doi.org/10.1111/1468-0084.61.s1.14
39. Pesaran, M. H. (2004). General diagnostic tests for cross-section dependence. CESifo Working Paper No. 1233.
40. Pesaran, M. H. (2007). A simple panel unit root test. Journal of Applied Econometrics, 22(2), 265–312.
41. Pesaran, M. H., Shin, Y., & Smith, R. J. (2001). Bounds testing approaches. Journal of Applied Econometrics, 16(3), 289–326.
42. PNUD. (2014). Stratégie du PNUD pour la promotion de l'égalité des sexes. PNUD.
43. Roodman, D. (2009). How to do xtabond2. The Stata Journal, 9(1), 86–136.
44. Sen, A. (1999). Development as freedom. Oxford University Press.
45. Sertyesilisik, B. (2023). Women empowerment as a key to support achievement of the sustainable development goals and global sustainable development. In Gender Inequality and its Implications on Education and Health: A Global Perspective. 153-163.
46. Tilman, D., Socolow, R., Foley, J. A., Hill, J., Larson, E., Lynd, L., Pacala, S., Reilly, J., Searchinger, T., Somerville, C., & Williams, R. (2009). Énergie. Biocarburants bénéfiques : le trilemme alimentaire, énergétique et environnemental. Science (New York, N.Y.), 325(5938), 270–271. https://doi.org/10.1126/science.1177970
47. Women, U. N. (2021). Empowering women at work: government laws and policies for gender equality. https://policycommons.net/artifacts/1469225/empowering-women-at-work/2120184/
48. Wheeler, T., & von Braun, J. (2013). Climate change impacts on global food security. Science, 341(6145), 508–513.
49. Zakari, S., et al. (2022). Adaptation strategies to climate change. Sustainability, 14(5).
50. Zhuang, D., et al. (2022). Land-use and food security in energy transition. Frontiers in Sustainable Food Systems.