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The Interconnected Dynamics of Agricultural Growth, Employment, Renewable Energy, and Carbon Emissions: Evidence from Morocco

Lamharher Redouane[1]*, Ritahi Oussama[2], Echaoui Abdellah[1]

[1]*University Mohammed V – Rabat*
[2]*University Hassan II – Casablanca*
* Corresponding Author

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Abstract

The Environmental Kuznets Curve posits that as economies develop, environmental pressures initially increase but subsequently decrease as incomes rise and societies adopt stricter environmental policies. This study explores the impact of CO2 emissions, renewable energy consumption, employment in the agricultural sector, and trade openness on agricultural GDP in Morocco. We utilized annual data from 1990 to 2022 and employed the ARDL approach to analyze these long-term relationships. Our findings indicate that CO2 emissions have a significant negative impact on agricultural GDP. Similarly, renewable energy consumption is associated with a decrease in agricultural GDP. Conversely, employment in the agricultural sector did not show a significant effect on agricultural GDP. Lastly, trade openness has a significant positive impact on agricultural GDP. These conclusions underscore the importance of policies aimed at reducing CO2 emissions, optimizing the use of renewable energies, and promoting trade to foster sustainable growth in Morocco's agricultural sector.

Keywords: EKC, ARDL, Agricultural GDP, CO2 Emissions

1. Introduction

Energy is the driving force behind every modern economy. It is a crucial contributor to nearly all the goods and services we rely on today. Stable and reasonably priced energy supplies are vital for maintaining and improving the standard of living for billions of people around the world. A recent report from the World Economic Forum described energy as the oxygen of the economy: "Without heat, light, and electricity, you can't build or operate the factories and cities that provide goods, jobs, and homes, nor can you enjoy the comforts that make life more pleasant and livable."

Several energy-related challenges exist, but three main issues dominate current energy discussions. First, fossil fuels are a finite resource. Although there are still large reserves of coal, oil, and natural gas, growing demand and limited supply make it inevitable that these reserves will one day run out. Therefore, it is important to seek alternative energy sources.

Second, there is the issue of energy security faced by energy-importing countries. The fact that major energy reserves are concentrated in certain parts of the world poses risks for many countries in terms of the reliability of their energy supply. The energy crises of the 1970s served as a wake-up call for many, and the recent uprisings in the Arab world have once again demonstrated that heavy reliance on energy imports is neither safe nor stable and can also be politically damaging.

Third, although opinions vary, it is highly likely that the use of fossil fuels is altering the climate. One of the biggest contributors to climate change is the rise in greenhouse gases (GHGs) in the atmosphere, particularly carbon dioxide (CO_2) resulting from the combustion of fossil fuels (coal, oil, and natural gas). It is widely accepted that unless drastic actions are taken to reduce global warming, the world could face an environmental catastrophe. All these issues are important, but the one receiving the most global attention is climate change.

The actual contributions of certain renewable energies to CO_2 reduction can be questioned. Some renewable energies such as hydropower, geothermal, and biomass are reliable and easily predictable, so there is no doubt about their contribution to reducing greenhouse gas (GHG) emissions. However, other popular renewables like wind and solar are associated with high intermittency and pose significant challenges in balancing their supply. White (2004) argues that fluctuations in wind power production must be offset by operating fossil thermal power plants below optimal efficiency levels to stabilize the grid (backup reserve). Therefore, although electricity produced by wind is itself CO_2-free, the savings for the entire power system are not proportional to the amount of fossil-based electricity it replaces. Operating fossil thermal capacity as a backup reserve emits more CO_2 per kWh than if the plant operated optimally, thereby canceling out much of the benefits of wind energy. This was confirmed by Danish electricity providers Elsam and Jutland during a meeting with the Danish Wind Energy Association and the Danish government, where they stated that increasing wind capacity did not reduce CO_2 emissions (White, 2004).

However, it is important to note that renewable energies with high intermittency (wind and solar) are only part of a larger renewable energy system (including biomass, hydropower, and geothermal), whose contributions are less disputed. It is also worth noting that Denmark has one of the highest shares of stochastic renewable energy (wind) in its energy mix.

Given the importance of the above-mentioned issues and the associated challenges, it is not surprising that the relationship between agricultural economic growth, environmental pollution, and energy consumption has been among the most debated topics in energy economics over the past decades. A significant body of research has examined the link between economic growth and energy consumption on one hand, and between economic growth and environmental pollution on the other. However, there is a lack of empirical studies investigating both relationships within a single framework. In particular, there is a significant lack of research that examines renewable energy consumption instead of aggregated energy consumption using modern econometric techniques associated with causality tests. Thus, given the importance of renewable energy supply as a potential panacea for emissions reduction, research that examines the causal relationship between renewable energy consumption, environmental pollution, and agricultural economic growth is needed.

Research on the nexus between agricultural economic growth, renewable energy supply, and CO_2 emissions is crucial for sustainable development and the fight against climate change. In many countries, similar to the case of Morocco, agriculture is a key pillar of the economy, providing jobs and food resources. However, this agricultural economic growth must be sustainable to avoid contributing to environmental degradation. By integrating renewable energies into agricultural systems, it is possible to reduce dependence on fossil fuels, lower energy costs, and mitigate CO_2 emissions. Renewable energies such as solar, wind, and biomass offer viable solutions to power agricultural equipment and rural infrastructure, promoting cleaner and more efficient production. This also contributes to combating global warming by reducing CO_2 emissions, which is essential for preserving agricultural ecosystems and biodiversity.

In-depth research on this nexus helps to understand the synergies and trade-offs among these three dimensions, thus offering strategies to promote sustainable agricultural economic growth while ensuring a transition to renewable energy sources and reducing the carbon footprint. It also helps guide public policies and investments toward sustainable agricultural and energy practices, ensuring a more resilient and equitable future for coming generations.

2. Literature Review

2.1 Environmental Kuznets curve

The Environmental Kuznets Curve (EKC) posits an inverted U-shaped relationship between various pollutants and per capita income, meaning that environmental degradation increases up to a certain point as income rises, and then begins to decline (Dinda, 2004). The EKC essentially reflects changes in environmental quality, technically measured, as a country's wealth evolves. The underlying assertion is that environmental quality deteriorates in the early stages of economic development or growth but improves at later stages. In other words, environmental pressure grows faster than income at the early stages of development and slows down relative to GDP growth at higher income levels (Lieb, 2003).

Global environmental concerns have received more attention than ever, as global warming and other environmental issues have become more severe. For all authorities responsible for environmental policy, it is now an urgent matter to understand and predict how environmental quality will evolve over time if the economy continues to grow (Kijima, Nishide & Ohyama, 2010).

EKC theory suggests that the process of economic growth is eventually expected to curb the environmental degradation caused during the early stages of development. This concept has led many researchers since the early 1990s to assume that every economy should focus on growth, as GDP is seen both as the cause and the remedy for environmental problems (Galeotti, Lanza & Pauli, 2006). The concept is also relevant to the issue of climate change. Climate change is undoubtedly a pressing problem, now widely recognized by experts, governments, and the public worldwide. The 1992 Rio Earth Summit and the 1997 Kyoto Protocol, along with subsequent developments, drew international attention to the harmful consequences of greenhouse gas emissions (Galeotti, Lanza & Pauli, 2006).

Carbon dioxide (CO_2) emissions are the most potent among greenhouse gases, and once released into the atmosphere, they contribute to climate change with potentially irreversible impacts on the environment (Müller-Fürstenberger & Wagner, 2007). Thus, the issue is closely related to the Environmental Kuznets Curve (EKC) concept, and many researchers have attempted to quantitatively investigate the relationship between CO_2 emissions and per capita income

(Müller-Fürstenberger & Wagner, 2007). Specifically for CO_2, the term "Carbon Kuznets Curve" (CKC) is used, which postulates that emissions initially increase with GDP, reach a peak at a certain income level, and then decline as income continues to rise—possibly because the willingness to pay for environmental quality increases with income.

During the first commitment period of the Kyoto Protocol (2008–2012), many industrialized countries pledged to reduce their emissions and were required to lower them by an average of 5% compared to 1990 levels. However, no such commitment was made by developing countries. At the heart of this position lies a long-standing debate between economic development and environmental quality. The issue is complex and depends on a multitude of different factors (Galeotti, Lanza & Pauli, 2006). This is why most studies on the topic have taken an empirical form to analyze and identify the factors responsible for any observed relationship (Panayotou, Peterson & Sachs, 2000).

The curve conveys a powerful message and could support developing countries in resisting binding emission reduction targets as proposed under the Kyoto Protocol (Galeotti, Lanza & Pauli, 2006). Therefore, in relation to CO_2 emissions, this matter has far-reaching implications that require extreme caution and careful consideration in analysis. The global nature of this pollutant and its critical role as a major driver of the greenhouse effect give special significance to the study of the relationship between CO_2 emissions and income.

Moomaw and Unruh (1997) compared EKC reduced-form models with structural models of per capita CO_2 emissions and per capita GDP. They found that, contrary to previous EKC studies, the change in elasticities was sudden and discontinuous, due to historical events such as the oil shocks of the 1970s and the policies that followed them, rather than a gradual shift. In their view, the N-shaped relationship they identified between emissions and income does not provide a reliable indication of future behavior.

Schmalensee, Stoker, and Judson (1998) found an inverted U-shaped relationship, with a peak within the sample, between CO_2 emissions (and per capita energy use) and per capita income. They decisively rejected the null hypothesis that income parameters for OECD and non-OECD countries are the same.

De Bruyn, van den Bergh, and Opschoor (1998) found that CO_2 emissions were positively correlated with economic growth and that emissions reductions were achievable through structural and technological changes in the economies of four wealthy countries. They found a balance between the positive influence of growth and the negative influence of structural and technological changes on emission levels. Based on their evidence, they concluded that the assumption that economic growth leads to improvements in environmental quality is not supported for the countries studied.

Agras and Chapman (1999) included energy (gasoline) prices and trade as independent variables in the model and found no significant evidence of an EKC within the income range of the sample.

Galeotti and Lanza (1999) estimated two alternative parametric functional forms, Gamma and Weibull, on three data samples for Annex I countries, non-Annex I countries, and the world as a whole. Although they were mainly focused on emissions forecasting, an inverted U-shaped relationship appeared in all cases.

Borghesi (2000) examined the impact of within-country income inequality on CO_2 emissions and the CO_2-income relationship. However, income inequality had a statistically insignificant impact on CO_2 emissions. They speculated that either income distribution is not necessarily linked to environmental degradation, or the positive and negative effects of income inequality on the environment tend to cancel each other out.

Perrings and Ansuategi (2000) conducted a cross-sectional analysis for 114 countries in 1990 and found a rising relationship between emissions and income. However, an additional variable—the share of agriculture in GDP—had a negative effect on emissions, meaning that when the economy depends more on the primary sector, emissions are likely to be lower.

Panayotou, Peterson, and Sachs (2000) found an inverted U-shaped relationship between emissions and income for 17 developed countries using panel data analysis. They estimated various models by including different independent variables such as trade, non-residential capital stock, and population density. They also conducted time-series analysis for only two countries, the United States and the United Kingdom, and found an EKC pattern.

Dijkgraaf and Vollebergh (2001) questioned the homogeneity assumption across countries. Using data from 24 OECD countries, they decisively rejected the hypothesis that country-specific slopes are the same, even for small country groups. When individual time-series models were estimated, 11 out of 24 cases showed an EKC-like pattern.

Pauli (2003) noted that unjustified clustering of countries in panel data can lead to misleading conclusions about the EKC. He used a new statistical model—a hierarchical Bayesian specification—in which first-level parameters were country-specific autoregressive terms. Using data for OECD countries, he found that the same model does not fit all OECD countries.

2.2 Agricultural Economic Growth and Renewable Energy Supply

The foundations of the global economy rely on coal, natural gas, and crude oil, and the cost of oil production has increased. By raising product prices to reflect rising energy and raw material costs, the economy has made the necessary adjustments. The issue is that, although renewable energy sources have long been acknowledged in economic and social theory, they are still often viewed as a problem for the future (Kircher, 2019). One concern, despite years of discussions around decarbonization policies, is that a consensus on achieving this goal has not been reached (Khabbazan & Hokamp, 2022). Developed countries have adopted the use of renewable energy in agriculture; however, poorer countries still struggle with implementation due to technical and economic challenges (Rahman et al., 2022).

The discourse around renewable energy as a mitigation tool has gained traction across the continent due to the rapid increase in emissions. In a review study conducted by Lamb et al. (2021), examining greenhouse gas emission trends and drivers by sector from 1990 to 2018, it was found that agricultural activities increased emissions in Africa and that the trend was upward. This observation highlights the critical need for countries to invest in renewable energy. A study by Banks and Schäffler (2005) concluded that increasing the use of renewable energy would also reduce South Africa's dependence on fluctuating (and rising) costs of imported fuels. Considering the current volatility of fossil fuel prices due to geopolitical challenges, this instability will be difficult to manage in the future in the presence of additional shocks, with poorer countries bearing the brunt of the impact. The negative effects will be felt in the agricultural sector, which is currently dominated by small-scale farmers with limited resources.

Akinbami et al. (2021) also examined the state of renewable energy development in South Africa and concluded that the country possesses immense potential in biomass, wind, and solar energy, and that waste management systems and investments should be taken into account. The current challenge is that the focus has been on investments in wind and solar, while the potential of modern biomass remains untapped. Recent investments in South Africa have targeted solar and wind energy through the Renewable Energy Independent Power Producer Procurement Programme (REIPPP). The potential for biomass lies in the agricultural sector since farmers are the primary producers of this biomass. If this opportunity is explored, the agricultural sector would benefit, as farmers could generate their own energy, ultimately increasing production scale. This could reduce energy costs for farmers, and the surplus energy could also be sold to the national grid.

Moreover, Uhunamure and Shale (2021) conducted a SWOT analysis of renewable energy production in South Africa and concluded that the country's geographical position, political and economic stability, and policy implementation were strengths, while bureaucratic government processes, low awareness, and high investment costs were among its weaknesses. The lack of awareness identified in the SWOT analysis underscores the need for an aggressive government approach to promote renewable energy at all levels, with a special focus on farmers and businesses in rural areas to ensure no one is left behind in line with just energy transition goals. Over time, this would ensure the smooth adoption of renewable energy technologies.

Ibrahim et al. (2021) examined renewable energy production in Africa using Nigeria, Cameroon, Ghana, and South Africa as case studies. The study recommended tax exemptions on renewable energy to encourage production. While tax incentives for renewable energy use are important, the issue at hand is largely one of insufficient supply, which raises prices and discourages adoption. Thus, the South African government should focus more on incentivizing producers. In the agricultural sector, this initiative could reduce rural areas' dependence on the main grid and help build sustainable ecosystems in rural zones where most farms and biomass resources are located. The potential economic spillovers could be substantial in the future.

Aliyu et al. (2018) examined renewable energy development in Africa, focusing on South Africa, Egypt, and Nigeria, and recommended emphasizing technology, awareness, and skills development for renewable energy production. Given that renewable energy is a relatively new sector, skill shortages are a major issue and require a bottom-up approach in South Africa. This would require the development of renewable energy curricula—something that currently does not exist in vocational higher education institutions. These efforts could then integrate well with technical training, which would help accelerate technology transfer into the energy economy.

In Okumus et al. (2021), the association between renewable and non-renewable energy consumption and economic growth was estimated for G7 countries from 1980 to 2016 using the CS-ARDL method. The results predicted that renewable energy increases economic growth. Renewable energy supply and trade openness were excluded from the model. In Iran, a similar study was conducted to examine the links between renewable energy use, carbon emissions, and economic growth from 1975 to 2017 using a non-ARDL model. The results indicated that renewable energy boosts economic growth (Karimi et al., 2021). However, the study did not include trade or renewable energy supply.

Busu (2020) also analyzed the impact of renewable energy sources on economic growth in the EU using the ARDL technique. The results predicted that renewable energy increases economic growth. Magazzino et al. (2022) also evaluated renewable energy consumption, environmental degradation, and the economic growth nexus from 1990 to 2018 in Scandinavian countries using an FMOLS technique. The results showed a positive relationship between renewable energy and economic growth.

A study by Pata (2021), using the Fourier ADL test to examine the effects of agricultural practices, globalization, and renewable energy production on ecological footprints and CO_2 in BRIC countries from 1971 to 2016, found that globalization increased pollution while renewable energy improved the environment in Brazil. The study's conclusions reaffirmed the value of renewable energy.

Studies have shown that renewable energy consumption improves the economy. However, contrasting results have been observed in similar studies by Akram et al. (2021), Fotio et al. (2022), and Ozturk et al. (2022), using the PQR model, PMG–ARDL, and PVAR respectively, which concluded that renewable energy decreases economic growth.

3 Research Methodology

3.1 Model specification

The model specification aims to establish the functional relationships between the various variables of interest in the study: agricultural economic growth, CO_2 emissions, renewable energy, trade openness, and employment in the agricultural sector. The proposed model can be formulated as a multiple regression equation, where agricultural economic growth is the dependent variable and the other variables are the explanatory variables. Mathematically, the model can be expressed as follows:

$$EconomicGrowth = \beta_0 + \beta_1 Emissions\ of\ CO2 + \beta_2 Renewable\ Energy\ + \beta_3 Agri\_Employment\ + \epsilon$$

Where:

- β_0 is the intercept,
- β_1, β_2, β_3 are the regression coefficients representing the marginal impact of each explanatory variable on agricultural economic growth, and
- ε is the error term.

This specification allows for quantifying the individual effect of each factor while controlling for the others, thereby offering a better understanding of the complex dynamics between agricultural growth and environmental and economic influences. The use of stationarity tests and cointegration techniques is crucial to ensure that the coefficient estimates are reliable and that the observed relationships are not spurious.

3.2 Data and Sources

This section presents the data that will be used in the impact study on the relationship between agricultural economic growth, CO_2 emissions, and renewable energy. The study uses annual data covering the period from 1990 to 2022. The methodology includes time series stationarity tests and cointegration techniques to avoid misleading results.

Table 1: Data sources and period

Variable	Period	Source
Agricultural GDP	1990–2022	World Bank
CO_2 Emissions	1990–2022	World Bank
Employment in the Agricultural Sector	1990–2022	World Bank
Renewable Energy Supply	1990–2022	International Energy Agency

The study is based on annual data collected over a 32-year period from 1990 to 2022. These data include five key variables:

- Agricultural Economic Growth: Measured by the agricultural value added as a percentage of GDP. This data is obtained from the World Bank economic databases.
- CO_2 Emissions: Measured in metric tons per capita or per unit of GDP. Common sources for this data include the CO_2 emissions database of the International Energy Agency (IEA) and countries' environmental reports.
- Renewable Energy: Measured as a percentage of total energy consumption or in terms of energy production (e.g., megawatts of renewable energy produced). The data were obtained from the IEA.
- Employment in the Agricultural Sector: Measured as the percentage of the labor force employed in agriculture. These data are essential to evaluate the impact of agricultural growth and energy policies on rural employment. The source is the World Bank.

4 Results and Discussion

4.1 Unit Root Test

Examining the properties of time series before analyzing relationships between variables is crucial due to the challenges posed by non-stationary series in regression analysis. It is well established in the literature that an Ordinary Least Squares (OLS) regression can yield spurious results when data contain a unit root, except in the case of cointegration (Hamilton, 1994). Therefore, insufficient investigation into the presence of a unit root may lead to seemingly significant but actually meaningless or, at best, inaccurate estimates.

To avoid such spurious estimation, stationarity properties are verified using unit root tests, notably the Augmented Dickey-Fuller (ADF) test (Dickey & Fuller, 1979) and the Phillips-Perron (PP) test (Phillips & Perron, 1988).

Tests of Variables at Level

The table provides the results of the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root tests to assess the stationarity of the time series of the variables Log(Agri_PIB), Log(CO2), Log(EMP), Log(Energie), and Log(Trade) at level. The t-Statistic values indicate the strength of the test, while the P-value values determine the statistical significance of the test. The decisions are categorized as the process being considered a TS (Trend Stationary) process or a DS (Differency Stationary) process.

For the variable Log(Agri_PIB), the ADF and PP tests show a significance level below 5%, indicating that the series is stationary. The analysis of the test results indicates that the trend component of the test is significant, indicating that the

series is stationary around its trend. Therefore, Log(Agri_PIB) is a non-stationary process of type TS.
For the variables Log(CO2), Log(EMP), Log(Energie), and Log(Trade), the ADF and PP tests reveal significance thresholds below 5%, indicating non-stationarity for these time series.

Table 2: Stationarity results for variables at level

Variables	ADF t-Statistic	ADF P-value	PP t-Statistic	PP P-value	Decision
Log(Agri_PIB)	-6.307141	0.0001	-6.33144	0.0001	TS
Log(CO2)	-2.412254	0.1467	-2.81983	0.0667	DS
Log(EMP)	2.407614	0.9999	2.095776	0.9998	DS
Log(Energie)	-2.588303	0.2877	-2.63056	0.2704	DS

Tests of Variables: First Difference

The table presents the results of the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root tests to assess the stationarity of the time series of the variables Log(Agri_PIB), Log(CO2), Log(EMP), Log(Energie), and Log(Trade) at first difference. The t-Statistic values represent the strength of the test, while the P-value values indicate the statistical significance of the test. The order of integration indicates the number of differences needed to make the time series stationary.
For the variable Log(Agri_PIB), the trend component was removed from the original series and the ADF and PP tests show high t-Statistics and very low P-values (0.000), leading to the decision that the time series is stationary.
For the variables Log(CO2), Log(EMP), Log(Energie), and Log(Trade), the ADF and PP tests reveal high t-Statistics and very low P-values (0.000), indicating that these time series are stationary. The order of integration for these variables is also I(1), suggesting that one difference is necessary to reach stationarity.

Table 3: Stationarity results for first difference

Variables	ADF t-Statistic	ADF P-value	PP t-Statistic	PP P-value	Decision	Order of Integration
Log(Agri_PIB)	-6.307141	0.000	-6.33144	0.000	TS	I(1)
Log(CO2)	-9.10811	0.000	-10.7948	0.000	DS	I(1)
Log(EMP)	-4.654867	0.004	-4.57102	0.005	DS	I(1)
Log(Energie)	-5.281031	0.001	-5.84139	0.000	DS	I(1)

F-Bound Test

In the absence of I(2) higher-order variables in the equation, the F-Bound test examines whether a long-term relationship exists between the variables using the OLS technique, followed by a Wald test in Eviews 12.

Table 4: F-bound test results

Test Statistic	Value	Signif.	I(0)	I(1)
F-statistic	31.99905	10%	2.37	3.2
k	3	5%	2.79	3.67
		2.5%	3.15	4.08
		1%	3.65	4.66

The calculated F-statistic is 31.99, which is higher than the upper critical value of 4.66 at the 1% level. Thus, the null hypothesis of no cointegration is rejected, implying long-term cointegration relationships between the variables. This means there is a long-run relationship between AGRI_PIB, CO2, EMP, and ENERGIE, over the period 1990 to 2022 in Morocco.

4.2 Estimation Results

Long-Term Relationship Analysis

The following table provides a detailed analysis of the regression coefficients for each explanatory variable in relation to agricultural GDP, measured by the logarithm of agricultural GDP.
Firstly, the positive and statistically significant coefficient of LOGCO2 (0.5649) with a p-value well below 5% (0.0001) suggests a strong positive relationship between CO_2 emissions and agricultural GDP. This implies that, in the model considered, a 1% increase in CO_2 emissions is associated with approximately a 0.56% increase in agricultural GDP. This could reflect a scenario where economic and agricultural expansion is occurring alongside increased carbon emissions.
In contrast, the coefficient of LOGEMP is 0.1197, but with a high p-value (0.4788), indicating that employment does not have a statistically significant effect on agricultural GDP in the long run.
As for renewable energy consumption (LOGENERGIE), the coefficient is strongly negative (-0.8939) and statistically significant (p-value = 0.0004), suggesting a significant inverse relationship between renewable energy consumption and agricultural GDP. In other words, an increase in renewable energy use appears to be associated with a decrease in

agricultural output, possibly due to inefficiencies or transition costs in the energy structure affecting the sector.

Table 5: Long run relationship estimates

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LOGCO2	0.564857	0.081450	6.934994	0.0001
LOGEMP	0.119741	0.162048	0.738920	0.4788
LOGENERGIE	-0.893952	0.166116	-5.381483	0.0004
C	18.01802	1.096692	16.42943	0.0000

When comparing these findings with those reported by Tagwi Aluwani (2023), notable differences arise. While Aluwani found a positive impact of CO_2 emissions on agricultural GDP—which aligns with our results—the effect of renewable energy is similarly negative in both studies, suggesting that in the current context, renewable energy consumption might not yet be efficient or widespread enough to support agricultural growth. However, the lack of statistical significance of employment in our model differs from some studies where labor input plays a central role.

Short-Term Relationship Analysis

The following table presents the short-term estimation results, highlighting the immediate effects of changes in the explanatory variables on agricultural GDP. The coefficients of the first-difference variables (denoted as D) reflect how fluctuations in each variable impact the dependent variable over short horizons.

To begin with, D(LOGCO2) and its lags reveal a strong and statistically significant positive relationship with agricultural GDP in the short term. Specifically, D(LOGCO2) (1.72), D(LOGCO2(-2)) (1.44), and D(LOGCO2(-3)) (3.49) are all significant at the 1% level. This suggests that increases in CO_2 emissions are associated with increases in agricultural GDP, indicating a possible link between economic activity and environmental externalities in the short term. However, D(LOGCO2(-1)) is not statistically significant.

Turning to employment, the results are mixed. The current change in employment (D(LOGEMP)) and its lags at periods 2 and 3 have significant negative coefficients (e.g., −4.32, −2.77, −5.63), indicating that short-term increases in employment may coincide with declines in agricultural GDP. This could reflect inefficiencies or seasonality in labor absorption in the sector. Only D(LOGEMP(-1)) shows a positive and statistically significant effect, suggesting a possible short-term lagged benefit from prior employment increases.

Regarding renewable energy consumption, all the differences from the current period up to three lags (D(LOGENERGIE) through D(LOGENERGIE(-3))) exhibit positive and statistically significant coefficients, with particularly strong effects at lags 1 and 2. This indicates that increases in renewable energy usage contribute positively to short-term agricultural GDP growth, potentially reflecting improved energy access or efficiency gains in agricultural processes.

Table 6: Short run relationship results

Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(LOGCO2)	1.718385	0.224157	7.665987	0.0000
D(LOGCO2(-1))	0.148213	0.298440	0.496626	0.6314
D(LOGCO2(-2))	1.443190	0.318660	4.528930	0.0014
D(LOGCO2(-3))	3.493628	0.357044	9.784865	0.0000
D(LOGEMP)	-4.322174	0.657405	-6.574596	0.0001
D(LOGEMP(-1))	1.718701	0.747033	2.300703	0.0469
D(LOGEMP(-2))	-2.773893	0.618596	-4.484172	0.0015
D(LOGEMP(-3))	-5.634667	0.651263	-8.651913	0.0000
D(LOGENERGIE)	0.312714	0.121928	2.564744	0.0304
D(LOGENERGIE(-1))	1.064003	0.169499	6.277333	0.0001
D(LOGENERGIE(-2))	1.317659	0.127809	10.30961	0.0000
D(LOGENERGIE(-3))	0.753640	0.150927	4.993417	0.0007
CointEq(-1)*	-1.440113	0.094731	-15.20211	0.0000

Interestingly, the error correction term (CointEq(-1)) is negative and highly significant (−1.44, $p < 0.01$), confirming the existence of a long-term equilibrium relationship between the variables. Its magnitude suggests a very rapid adjustment speed, as over 144% of any short-term deviation from long-term equilibrium is corrected within one year. This implies a high level of responsiveness in the system toward restoring balance.

Finally, with an R^2 of 0.96, the model exhibits excellent explanatory power in the short term, indicating that the selected variables account for the vast majority of changes in agricultural GDP over the analyzed period.

4.3 Model validity

First, to detect whether the residuals are autocorrelated in the three regression models, the Breusch-Godfrey test was used. The null hypothesis of this test states that there is no autocorrelation in the residuals, while the alternative hypothesis assumes its presence. The null hypothesis is rejected if the computed value exceeds the critical value from the Fisher test or if the associated probability is less than 5%. According to the test results (F-statistic = 0.0138; Prob. F = 0.909), the probability associated with the Breusch-Godfrey test exceeds 5%. Therefore, we cannot reject the null hypothesis, which means there is no evidence of autocorrelation in the residuals.

Table 7 : Autocorrelation test results

Breusch-Godfrey Serial Correlation LM Test:			
Null hypothesis: No serial correlation at up to 1 lag			
F-statistic	0.013828	Prob. F(1,9)	0.9090
Obs*R-squared	0.041422	Prob. Chi-Square(1)	0.8387

Second, to test the normality of the residuals, the Jarque-Bera test was applied. The null hypothesis assumes that residuals follow a normal distribution. This hypothesis is rejected if the test statistic is significantly high or if the associated probability is below 5%. According to the results of the test, the probability is above the 5% threshold. Hence, we accept the null hypothesis, implying that the residuals are normally distributed.

Third, to assess whether the variance of residuals remains constant (homoskedasticity), the Breusch-Pagan-Godfrey test was performed. The null hypothesis posits that the model is homoskedastic (i.e., the variance of residuals is constant), while the alternative assumes heteroskedasticity. The null hypothesis is rejected if the Fisher test value or the associated probability is below 5%. In this case, the test produced a probability value greater than 5% (Prob. F = 0.9074). As such, we do not reject the null hypothesis and conclude that the residuals are homoskedastic.

Table 8: Heteroskedasticity test results

Heteroskedasticity Test: Breusch-Pagan-Godfrey			
Null hypothesis: Homoskedasticity			
F-statistic	4.037116	Prob. F(16,10)	0.0151
Obs*R-squared	23.38040	Prob. Chi-Square(16)	0.1039
Scaled explained SS	2.430112	Prob. Chi-Square(16)	1.0000

Finally, the stability of the model was tested using the Cumulative Sum (CUSUM) and Cumulative Sum of Squares (CUSUMSQ) tests. These tests assess whether the model's coefficients remain stable over time. The null hypothesis in this context states that the vector of coefficients remains unchanged throughout the study period. According to Bahmani-Oskooee and Ng (2002), if the plots of the CUSUM and CUSUMSQ statistics remain within the 5% significance boundaries, the null hypothesis of parameter stability cannot be rejected. The results of these tests confirmed that the regression model is stable over the period of analysis, as both test plots remained well within the critical bounds.

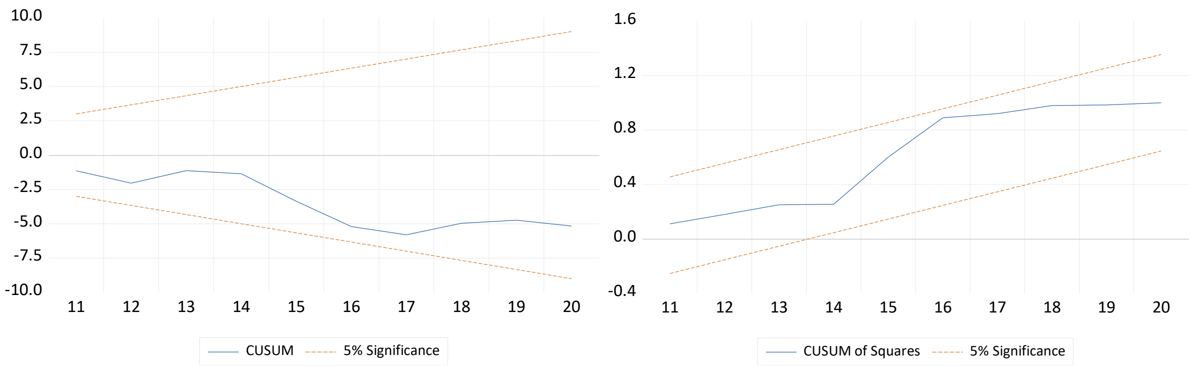

Figure 1: Stability test results

5 Conclusions and Recommendations

Although agricultural economic growth and renewable energy consumption in various economic sectors have been extensively studied, the role played by renewable energy sources in the agricultural economic growth of a country has received less attention, particularly in Africa. In this study, we analyzed the short- and long-term causal relationships between renewable energy consumption and Morocco's economic growth, as measured by real gross domestic product.

This study examined several explanatory variables in relation to agricultural GDP, measured by the logarithm of agricultural GDP. The results provide important insights into the relationships between these variables and the economic performance of the agricultural sector in Morocco.

First, the analysis revealed a significant inverse relationship between CO_2 emissions and agricultural GDP. The negative coefficient of $LOGCO_2$, associated with a very low p-value, suggests that CO_2 emissions have a negative impact on agricultural GDP over time. This indicates that policies aimed at reducing CO_2 emissions could potentially stimulate economic growth in the agricultural sector.

In contrast, employment, represented by the coefficient of LOGEMP, was not found to be statistically significant in its long-term impact on agricultural GDP in the model considered. This highlights that other factors may play a more important role in determining the economic performance of the agricultural sector.

Renewable energy consumption, measured by LOGENERGIE, was also examined. The results showed a significant negative relationship between energy consumption and agricultural GDP. This implies that a decrease in energy consumption is associated with an increase in agricultural GDP. These results suggest that policies promoting the use of renewable energies could help support the growth of the agricultural sector.

Finally, the analysis also highlighted a significant positive relationship between trade, represented by LOGTRADE, and agricultural GDP. This suggests that increased trade is associated with higher agricultural GDP, emphasizing the importance of trade for the economic development of the agricultural sector.

In light of the findings of this study, several recommendations can be proposed to strengthen sustainable agricultural growth in Morocco. First, it is essential to implement effective policies aimed at reducing CO2 emissions in the agricultural sector by promoting sustainable farming practices and improving energy efficiency. At the same time, actively promoting the integration of renewable energies into farming operations would not only reduce the carbon footprint but also improve resilience to fluctuations in energy costs. Although employment in the agricultural sector did not show a significant impact on agricultural GDP in this study, it remains crucial to strengthen initiatives that support rural employment and agricultural entrepreneurship. Moreover, facilitating trade openness and market access for agricultural products is vital to stimulate the sector's productivity and competitiveness.

In light of the findings of this study, several recommendations can be proposed to strengthen sustainable agricultural growth in Morocco. Policy Recommendations

First, the study's results underline the importance of adopting low-carbon agricultural practices. Since CO_2 emissions have shown a significant positive correlation with agricultural GDP, it is crucial to promote a model of growth that is less reliant on environmentally harmful practices. This includes investing in sustainable farming techniques such as precision agriculture, conservation tillage, and organic inputs, as well as improving water and soil management. Such measures can help decouple agricultural productivity from greenhouse gas emissions, contributing to both economic and environmental sustainability.

Second, while renewable energy is often seen as a tool for sustainable development, the negative relationship identified in this study between renewable energy consumption and agricultural GDP suggests the need for better integration of renewable technologies within the agricultural sector. This could be addressed by designing energy solutions specifically adapted to agricultural needs—such as solar-powered irrigation systems, cold storage, and food processing units—while also providing the technical training, financial support, and infrastructure necessary for their effective use. Simply increasing renewable energy consumption is not sufficient; its application must be strategic, targeted, and aligned with the operational realities of farmers.

Third, the limited role of employment in influencing agricultural GDP points to potential challenges related to labor productivity, skills mismatch, or the informal nature of agricultural work. As a result, policymakers should prioritize rural education and vocational training programs that align with modern agricultural practices. Moreover, encouraging agricultural entrepreneurship, particularly among youth and women, could contribute to a more dynamic and competitive sector. Boosting the efficiency and productivity of labor—rather than merely increasing the number of workers—is essential for long-term impact.

Finally, a more integrated approach is needed—one that recognizes the interdependence between energy systems, environmental management, human capital, and agricultural performance. Coordinated policies that foster innovation, ensure energy accessibility, and support institutional frameworks are crucial to unlocking the full potential of Morocco's agricultural sector. Such strategies should also be adaptable to the specific regional and ecological contexts within the country, recognizing that one-size-fits-all solutions may not be effective in addressing the complex challenges facing rural economies.

Conflict of Interest

The authors declare that they have no conflicting interests

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Ethical considerations

The article followed all ethical standards appropriate for this kind of research.

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