Economic and Technological Drivers of Sustainable Agriculture: Evidence from a Developing Country Context

Tartar Saif eddine[1♦], **Helimi Sarra**[2]

[1] Entrepreneurship and Organization Management Laboratory, University of Tebessa (Algeria)
E-mail: saifeddine.tartar@univ-tebessa.dz

ORCID:https://orcid.org/0009-0000-5714-2235

[2] Entrepreneurship and Organization Management Laboratory, University of Tebessa (Algeria)
E-mail: sarra.helimi@univ-tebessa.dz

ORCID:https://orcid.org/0009-0003-1963-9605

Received: 25/05/2025 **Accepted: 05/07/2025** **Published:20/07/2025**

Abstract:

The study aimed to identify the economic and technological factors influencing sustainable agricultural development in Algeria during the period 1991–2023. To achieve this, an economic analysis was conducted to examine the relationship and impact of these factors. The descriptive method was employed to define key concepts related to sustainable agricultural development and to highlight the most significant economic and technological factors. In addition, the empirical method was adopted using the Autoregressive Distributed Lag (ARDL) model to analyze the time-series data.

The findings indicate that agricultural development in Algeria during the study period exhibited characteristics of sustainability, driven primarily by the availability of key economic and technological factors. These factors contributed significantly to the overall advancement of the agricultural sector. Moreover, the results reveal a symmetric effect of both economic and technological variables on agricultural output, which serves as a representative indicator of sustainable agricultural development in Algeria over the 1991-2023 period.

Keywords: Sustainable agricultural development, agricultural output, food Gap, agricultural exports and imports, agricultural mechanization, ARDL methodology.

♦ **Corresponding author.**

1. Introduction:

Agriculture has long held vital importance across nations and societies, regardless of whether their economies are advanced or developing. Even primitive societies engaged in agriculture as a means of meeting essential needs such as food and clothing. Nevertheless, agriculture historically remained limited to a small segment of the population and did not receive substantial attention within the broader national economy—an economy that is frequently subjected to crises and declining growth rates. These recurring challenges have increasingly prompted efforts towards innovation and the adoption of alternative strategies to boost income and diversify sources of revenue. Among these strategies is sustainable agriculture, commonly defined as the production of food and both plant and animal products through the use of advanced technological techniques. In essence, this involves integrating globalized practices into the agricultural sector to enhance economic profitability. Such practices enable farmers and agricultural entrepreneurs employ innovative techniques in land preparation, pursue intensive production, and adopt recycling methods—such as reusing crop and animal waste as fertilizers—to enrich the soil and combat desertification.

Sustainable agricultural development has become a high priority within broader development strategies, as it constitutes a significant source of income for a large proportion of the population in many countries. Consequently, achieving sustainable development year after year requires an in-depth understanding of the factors that both influence and are influenced by it, whether economic, social, political, or technological in nature.

Algeria is among the rentier states that rely heavily on oil revenues, rendering its economy vulnerable fluctuations in global oil prices. This undermines economic stability, despite the country's abundance of untapped natural resources and its considerable agricultural potential. In response, Algeria has adopted a policy of economic diversification to reduce dependence on hydrocarbons. This has included the implementation of a series of investments in the agricultural sector, in an effort to stimulate economic activity and achieve the long-term goals of sustainable economic development.

1.1. The Problematic of the Study:

The economic and technological factors influencing the agricultural sector, and influenced by it in turn, vary significantly depending on the specific variables that constitute them. Given that Algeria is among the countries that have directed considerable efforts toward the agricultural sector as a means to achieve economic balance across various sectors and to respond to external shocks—particularly oil crises—the central research problem of this study can be framed as follows:

What is the impact of economic and technological factors on sustainable agricultural development in Algeria during the period 1991–2023?

Based on this research question, the following hypothesis is proposed:

Among the most significant economic factors are labor force, gross domestic product (GDP), investment expenditure, and increased production aimed at closing the food gap. These, along with technological factors such as the adoption of modern technologies and support for agricultural extension services, have a comprehensive impact on sustainable agricultural development.

1.2.Significance of the Study

The significance of this study lies in the fact that agriculture remains one of the longstanding and relevant area interest for economists seeking to achieve both sustainable development and food security. Reducing reliance on oil resources and enhancing productivity through the efficient use of natural resources are central to strengthening the national economy. In this context, harnessing technological innovation and leveraging economic variables within the agricultural domain can play a pivotal role in diversifying agricultural production, revitalizing domestic and international markets, and meeting the industrial sector's needs—since agriculture constitutes a critical outlet for such industries.

1.3.Objectives of the Study

This study seeks to achieve several key objectives:

- To explore the theoretical concepts of key economic and technological factors affecting sustainable agricultural development;
- To examine the impact of these factors on sustainable agricultural development;
- To analyze the effects of economic and technological variables on agricultural development in Algeria during the period 1991–2023 using econometric methods.

1.4. Methodology and Tools of the Study

The study relies on the descriptive approach to examine theories related to agricultural development and the various influencing factors, as well as to highlight their role in achieving sustainable development. Additionally, the econometric approach is employed to investigate the relationships between the variables under study during the period 1991–2023. The empirical analysis is conducted using ***Stata 17*** and ***EViews 13*** software.

1.5.Applied Literature

Studies examining the relationship between agricultural technologies and sustainable development have produced varied findings. Agriculture, as a sector, is broadly recognized as a key contributor to economic and social development, and remains the main source for meeting food needs, creating employment opportunities, and addressing unemployment—particularly across developing countries and transitional economies. In recent years, while considerable attention has been given to liberalization and economic reform, there has also been renewed emphasis on formulating and implementing new agricultural strategies and policies.

For instance **(OLABINJO & OPATOLA, 2023)** analyzed the potential of sustainable agricultural practices and their contribution to building a resilient and prosperous economy. They investigated the connections between sustainable agriculture, economic development, and environmental protection, concluding that agriculture-based sustainability helps mitigate the negative effects of farming practices on ecosystems. It also supports long-term ecological stability, enhances resilience in farming systems, and improves farmers' profitability and market flexibility by reducing input costs and capitalizing on the growing consumer demand for sustainably produced food. Such practices also contribute to food price stability, reduce market shock risks, and promote broader economic stability.

In another study, **Smedescu et al. (2023)** conducted a bibliometric analysis on the intersection of sustainability and profitability in both conventional and ecological agriculture. Their findings emphasized the dominance of ecological agriculture as the more sustainable model, while also identifying underexplored areas and challenges in assessing profitability. Additionally, the study highlighted the role of high-tech solutions and chemical inputs in boosting yields, but also addressed doubts regarding the economic viability of environmentally conscious farming models. Another related study **by** Sukayat et al. (2023) emphasized that farmer participation and education are essential for adopting sustainable agricultural systems in Indonesia, particularly in reducing chemical use. Based on interviews with 360 farmers and regression modeling, it found that education and engagement in farmer groups significantly influenced sustainability adoption.

Buzoianu et al. (2024) explored the optimal balance between four critical systems—social, economic, technological, and environmental—in the context of long-term sustainable development. They assessed how demographic and environmental factors affect agriculture and rural regions, and concluded that increasing global food demand is being challenged by accelerated urbanization, rising energy and fertilizer costs, water scarcity, and climate change. Their findings underscore the complex interrelations among these systems and the importance of adaptive strategies to maintain a sustainable equilibrium between growth, environmental protection, and human well-being.

Li et al. (2022) conducted a structural model analysis (PLS-SEM) of sustainable agricultural mechanization (SAM) in Hubei, China. Their results indicated that economic variables had the greatest influence, while government policies were the main drivers of agricultural development, and environmental factors played a dominant role in long-term sustainability outcomes.

Studies by **(Roger D. Norton, 2004)** and **(Douglas, Parente, & Rogers, 2002)** focused on the broader role of agriculture in development. Douglas et al. proposed that low agricultural productivity can significantly delay industrialization, reduce per capita income, and impair national development. Conversely, gains in agricultural productivity may accelerate industrial transitions and improve relative income levels—especially in the short term.

(Newman, Singhal, & Tarp, 2020) explored agricultural transformation in low-income contexts, using Vietnam as a case study. They found that well-functioning financial markets played a critical role in helping rural households cope with climate shocks. Their analysis highlighted the long-term effects of exposure to such shocks on household investment behavior and the potential of agricultural insurance as a policy tool **(Durbar, 2016).**

(Huong, Chuah, & Feeny, 2021)analyzed the adoption of sustainable agricultural practices (SAPs) using probabilistic models with farmer-level fixed effects. Their findings showed that peer learning, knowledge transfer through extension agents, and farmers' knowledge of land and soil quality were significant predictors of SAP adoption.

(Hoshide, 2023) demonstrated that sustainable agricultural development can be economically viable while also reducing environmental harm and improving community well-being. The study also raised concerns about the scalability and inclusiveness of "economies of scale" approaches, arguing instead for "economies of scope," where diversified production systems increase efficiency and reduce the need for resource-intensive expansion.

In summary, a review of the literature reveals that while studies differ in their contexts, samples, and analytical methods, they broadly agree on the significant influence of economic and technological factors on agricultural sustainability. Most studies have used an empirical (econometric) approach, although they vary in how sustainability is measured and operationalized. These studies share a common objective: to examine the influence of economic and technological variables on sustainable agricultural development, though they diverge in terms of geographical focus, data analysis techniques, and sample characteristics.

Given this background, the current study contributes by focusing on the Algerian context and applying a comprehensive econometric model to measure the relationship between agricultural technology and sustainable agricultural development using time-series data from 1991 to 2023. It adopts the Autoregressive Distributed Lag (ARDL) methodology, supported by robust data, to explore the dynamics of agricultural development and its relationship with technological indicators, thereby providing empirical evidence to guide economic policy making.

While theory suggests that agricultural technology has the potential to enhance sustainable agricultural development, its actual impact remains uncertain. Much of the current literature emphasizes linear relationships and average effects, often overlooking non-linearities and heterogeneity in agricultural growth. Additionally, few studies have explored the underlying mechanisms through which agricultural technology influences sustainability outcomes.

Thus, this paper seeks to fill that gap by conducting an empirical investigation using Algerian regional data. It aims to chart a path for enhancing agricultural sustainability through innovation, offering both theoretical contributions and practical implications for development policy**.**

2. The theoretical framework of the study The Theoretical Aspect of the Study

Achieving the United Nations Sustainable Development Goal of eradicating hunger by 2030 will require a substantial increase in agricultural productivity. However, such progress must not come at the expense of other SDGs. In particular, minimizing the environmental impact of economic and technological factors on agricultural development presents a major challenge.

A historical analysis of the agricultural sector reveals that the dominance of traditional farming practices since the 1960s has led to numerous problems, resulting in unsustainable patterns of agricultural development—especially in developing and underdeveloped countries. This has, in turn, prompted collective efforts to achieve development goals by revitalizing the agricultural sector and integrating technological advancements.

2.2. Sustainable Agricultural Development

In most cases, there is no clear distinction between the terms *agricultural development* and *sustainable agricultural development*, as both ultimately refer to increasing agricultural production while addressing environmental challenges. However, some researchers have proposed differing definitions.

The sustainable agriculture approach aims to enhance sustainability in agriculture, fisheries, and forestry sectors by conserving land, water, plant and animal genetic resources, and utilizing technologies that are non-degrading, economically viable, and socially acceptable **(Doornbos, 2000, p. 13)**.

Agricultural development can thus be described as a continuous process of transformation within the structures of the agricultural sector, aiming is to mobilize all productive capacities, improve farming practices, and organize various agricultural services.

Sustainable agricultural development is defined as a system that can continuously evolve to maximize both human benefit and resource use efficiency, while maintaining a favorable environmental balance. In other words, sustainable agriculture links production with the conservation of limited resources and environmental protection, ensuring the needs of the present generation are met without compromising the welfare of future generations. **(Abu-Elnaga, 2009, p. 4)**

Another definition describes it as farming that preserves the environment, society, and the economy, with a focus on practices that do not harm soil, water, or air. For example, using natural fertilizers instead of chemical ones helps maintain soil health and reduces pollution **(Olabinjo & Opatola, 2023, pp. 319 - 320)**.

It has also been defined as “a combination of the planned use of resources employed in agricultural production and efforts to conserve or enhance the existing resource base in order to prevent environmental degradation and meet the changing needs of society.” **(eduardoJ.T, 1991, p. 09)**

Based on these definitions, sustainable agricultural development can be understood as an integrated agricultural system that incorporates environmental, economic, and social components in order to achieve comprehensive development goals. According to **(Anlauf, 2023, p. 639)**. the key objectives of sustainable agricultural development include :

- Optimal use of natural and human resources in rural areas;
- Engaging rural populations in identifying their needs and problems and finding suitable solutions;;

- Creating new job opportunities by increasing economic investments in the agricultural sector;
- Equitable distribution of wealth and power;
- Combating rural-to-urban migration;
- Prompting integration among all economic sectors;
- Enhancing sustainable practices to ensure food security by securing reliable access to safe food, reducing dependency on external inputs, and encouraging innovation through research into alternative, resource-efficient, and economically viable agricultural methods.

2.2.1. Economic and Technological Factors Affecting Sustainable Agricultural Development

The factors influencing sustainable agricultural development are diverse and vary and depending on the specific impacts they have on the agricultural sector. In general, these factors are represented by variables within the broader macroeconomic framework of a given country over a defined period of time.

2.2.2. Economic Factors

Economic factors are variables that, collectively, reflect indicators of macroeconomic balance. **(Snell, 2020, pp. 1-3)** these include:

- **Development of agricultural labor force and its relative importance compared to total employment**

The agricultural population represents a major source of human labor for the agricultural sector. Therefore, transformation strategies are expected to focus on this group by establishing agricultural training and qualification centers. The relative importance of agricultural labor can be assessed using mathematical formulas that indicate either a contraction or expansion in its share compared to the total workforce.

- **Agricultural investment spending**

Investment spending in agriculture is considered one of the crucial drivers of agricultural development and a key factor for improving the sector.

- **Total agricultural credit**

Agricultural credit is essential for revitalizing, purchasing, and reclaiming agricultural land. It also supports soil plowing, irrigation and drainage projects, afforestation, vegetable and fodder crop cultivation, and livestock breeding—all of which contribute to expanding agricultural production and increasing livestock wealth.

- **Agricultural Output and Its Relative contribution to GDP**

Agricultural output is a core pillar of economic development. Its growth signals the overall advancement of the sector. Analyzing its relative importance involves assessing whether its share in GDP is shrinking or growing—often a reflection of the relative expansion of the other sectors.

- **Agricultural Area (in million hectares)**

In its narrow definition, this refers to land suitable for cultivation, irrigation, and primary production. In a broader sense, it encompasses the entirety of the natural landscape, including land, subsurface resources, and the biosphere above.

- **Per capita Share of Total Agricultural Output Value**

This variable reflects the impact of sustainable agricultural development, with increases typically indicating higher investments in the sector.

- **Development of the Average Monthly Income of Agricultural Workers**

This is a key indicator of sustainable agricultural development in any society that values the agricultural sector.

- **Growth in total GDP**

A fundamental macroeconomic indicator, GDP growth reflects overall economic performance and national development trends.

In addition to the above, other relevant economic indicators include:

- **The food gap;**
- **Agricultural imports;**
- **Agricultural exports;**

2.2.3. Technological Factors

Technological factors play a critical role in enhancing sustainable agricultural development. **According to Udimal et al. (2017, pp. 139-140),** these factors include

- **Biotechnology**

Biotechnology involves the study of genes and genetic material, including recombinant DNA techniques, tissue and embryo culture, and other related methods. These technologies serve as key tools for improving agricultural productivity and enhancing crop and livestock performance.

- **Remote Sensing Technology**

This technology can be employed to support agricultural development by monitoring climate conditions, tracking environmental changes, and mapping land and water resources. Such data provide essential inputs for effective agricultural planning and resource allocation.

- **The application of scientific research in agriculture**

This refers to the integration of scientific expertise in solving agricultural challenges, including soil degradation, desertification, and drought. By mobilizing qualified researchers and institutions, agricultural innovation and resilience can be significantly advanced.

- **Agricultural Mechanization**

Mechanization involves the use of modern machinery—such as tractors and plows—to rehabilitate and cultivate agricultural land more efficiently. These technologies reduce labor intensity, save time, and increase productivity through more systematic and timely operations.

3. Applied Aspect of the Study

The main objective of this study is to examine the relationship between agricultural technology and sustainable agricultural development in Algeria over the period 1991-2023. To achieve this goal, several variables were employed, drawn from various sources including the Arab Organization for Agricultural Development and the World Bank. These variables include:

- **Agricultural Output** (**GAP)**;
- **The food Gap in Agricultural Crops** (**FG**);
- **Arable Land Area** (**AW**);
- **Agricultural Mechanization** (**AM**);
- **Agricultural Imports** (**IMP.AG**);
- **Agricultural Exports** (**EXP.AG**).

Accordingly, the model equation that captures the relationship between the dependent and independent variables can be mathematically expressed as follows:

$$gap = \alpha_0 + \alpha_1 am + \alpha_2 aw + \alpha_3 imp.ag + \alpha_4 exp.ag + \varepsilon_t$$

Where:

- **α** and **β**: the model parameters **(coefficients);**
- ε_t: the stochastic **(random)** error term.

3.2.Correlation Matrix:

Before proceeding to analyze the statistical effect of the stationary variables on the dependent variable, it is essential to first examine the correlations among the variables under study. This allows for better understanding of the relationship between all variables and the relative importance of each. Correlation indicates the strength and direction of the relationship between two or more variables. The appropriate type of correlation matrix depends largely on the nature of the variables being analyzed. The following table presents the correlation results:

Table (1): Correlation Between Variables

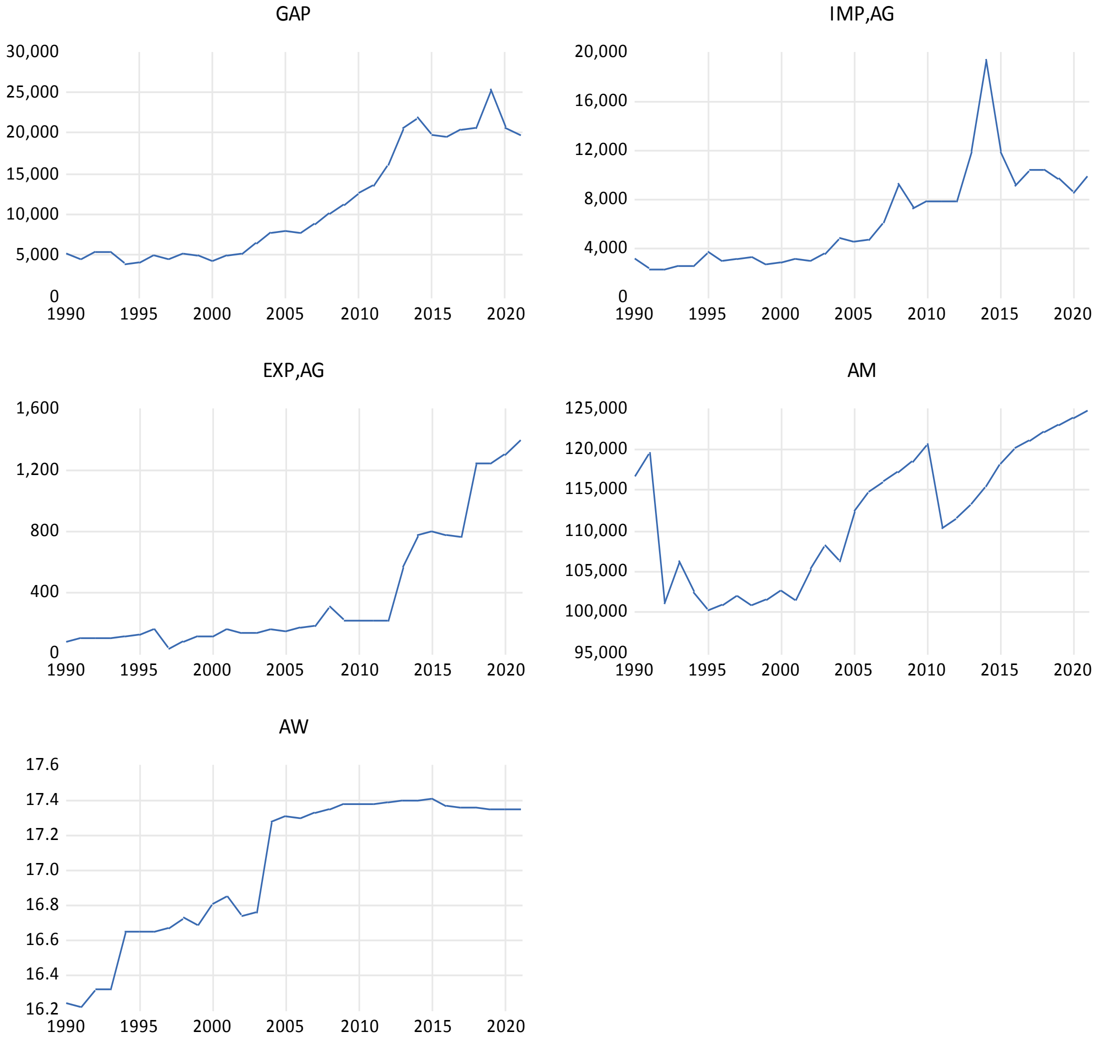
	GAP	EXP_AG	IMP_AG	FG	AM	AW
GAP	**1.000000**					
EXP_AG	0.879418	**1.000000**				
IMP_AG	0.481300	0.569796	**1.000000**			
FG	-0.047857	-0.016106	0.002011	**1.000000**		
AM	0.760672	0.717235	0.427602	-0.073675	**1.000000**	
AW	0.759555	0.566622	0.347004	0.132654	0.602071	**1.000000**

Source: Prepared by the authors based on Eviews13 output.

The correlation matrix reveals strong and positive relationships between the independent variables and the dependent variable, represented by agricultural output **(GAP).** Specifically, agricultural exports **(EXP_AG)** show a high correlation with **GAP** at **87.94%**, and agricultural imports **(IMP_AG)** are moderately correlated at 48.13%. Similarly, the correlation with agricultural mechanization **(AM)** and arable land area **(AW)** are also strong, measured at **76.06%** and **75.95%**, respectively. The only exception is the food gap **(FG)**, which exhibits a weak and negative correlation of **–0.047**, aligning with economic theory. This suggests that while most variables positively influence agricultural output, the negative association between **FG** and **GAP** may be attributed to factors such as increased agricultural production or effective food distribution, which in turn reduce the food supply gap.

3.3. Chart Number (01): Graph of the Variables

Fig (1): Graph of the variables



Source: Eviews13 Program Outputs

3.4.Stationary Test of the Time Series

Dickey and Fuller (1979) proposed a test to detect the presence or absence of a unit root, known as the Dickey-Fuller test. This test is commonly used to avoid spurious correlations between variables that may arise due to non-stationary time series. In the absence of stationarity, the regression obtained from time series variables may be misleading, even if the coefficient of determination (R^2) is relatively high. This issue stems from the fact that time series data often contain a trend component that reflects specific conditions affecting all variables—either in the same direction or in opposite directions (**Dickey & Fuller**, **1979**, **pp**. **421 – 431**).

As previously mentioned, a time series is considered stationary when it does not contain a unit root. The presence or absence of a unit root is tested across three models:

- with a constant,

- with a constant and a time trend
- and without either a constant or a trend

Two primary tests are employed: the Augmented Dickey-Fuller (ADF) test and the Phillips-Perron (PP) test. The ADF test was the first to examine the presence of a unit root, particularly within autoregressive models **(Dickey & Fuller, 1979, pp. 427-434)**. In contrast, Phillips and Perron (1988) proposed a non-parametric approach to correct for serial correlation, unlike the ADF test which uses a parametric method **(Phillips & Perron, 1988, p. 335)** Both tests rely on the following hypotheses:

- Null hypothesis (H_0): The time series is non-stationary (contains a unit root).
- Alternative hypothesis (H_1): The time series is stationary (does not contain a unit root).

The null hypothesis is accepted if the calculated value of the test statistic (ADF or PP) is greater than the critical value.

In this study, only the Phillips-Perron (PP) test is used to assess the stationarity of the variables

Tab (2): PP Test for Study Variables at the Level[1]

Model	UNIT ROOT TEST TABLE (PP)					
	At Level					
		GAP	EXP_AG	AW	AM	IMP_AG
With Constant	t-Statistic	-0.2783	3.0786	-2.1514	-1.1676	-4.8148
	Prob.	**0.9172**	**1.0000**	**0.2271**	**0.6755**	**0.0005**
		n0	n0	n0	n0	***
With Constant & Trend	t-Statistic	-2.1542	-0.0515	-1.2966	-3.5222	-6.3.48
	Prob.	**0.4970**	**0.9935**	**0.8701**	**0.0544**	**0.0001**
		n0	n0	n0	*	***
Without Constant & Trend	t-Statistic	1.1948	4.5061	1.9801	0.3068	-3.8181
	Prob.	**0.9369**	**1.0000**	**0.9866**	**0.7681**	**0.0004**
		n0	n0	n0	n0	***
Notes: (*)Significant at the 10%; (**)Significant at the 5%; (***) Significant at the 1%. and (no) Not Significant						
*MacKinnon (1996) one-sided p-values.						

Source: Prepared by the researchers based on the outputs of Eviews13.

As shown in Table (02), we reject the null hypothesis and accept the alternative hypothesis for the variable *agricultural imports (IMP_AG)*. This result indicates that the time series for agricultural imports is stationary at level across all three model specifications

[1] *(*) Significant at the 10% significance level;*
(**) Significant at the 5% significance level;
(***) Significant at the 1% significance level;
(no) Not significant.

(with constant; with constant and trend; without constant and trend), since the p-values for all models are less than the 0.05 threshold, and thus the series does not contain a unit root. Conversely, the variables GAP (agricultural output), EXP_AG (agricultural exports), AW (arable land area), and AM (agricultural mechanization) exhibit non-stationarity at level across all models. Their associated p-values exceed the 0.05 significance level, indicating the presence of a unit root and hence non-stationarity at level. This is consistent with economic theory, as macroeconomic time series often follow stochastic trends.

To achieve stationarity, these series will be differenced once, i.e., transformed to their first difference, I(1). The unit root tests will then be applied again to the differenced data. The results of this second round of tests are presented in the following table:

Tab (3): PP Stationarity Test at First Difference.

Model	UNIT ROOT TEST TABLE (PP)					
	At thefirstdefference					
		GAP	EXP_AG	AW	AM	IMP_AG
With Constant	t-Statistic	-5.3294	-5.1795	-5.7138	-6.8071	--
	Prob.	**0.0001**	**0.0002**	**0.0000**	**0.0000**	**--**
		***	***	***	***	--
With Constant & Trend	t-Statistic	-5.2442	-10.5357	-8.4063	-7.3323	--
	Prob.	**0.0010**	**0.0000**	**0.0000**	**0.0000**	**--**
		***	***	***	***	
Without Constant & Trend	t-Statistic	-4.9742	-4.6619	-5.1815	-6.8931	--
	Prob.	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**--**
		***	***	***	***	--
Notes: (*)Significant at the 10%; (**)Significant at the 5%; (***) Significant at the 1%. and (no) Not Significant						
*MacKinnon (1996) one-sided p-values.						

Source: Prepared by the researchers based on the outputs of Eviews13.

After applying the first difference transformation I(1)I(1)I(1), all time series variables become stationary at the 5% significance level across all three model specifications (with constant; with constant and trend; without constant and trend). This conclusion is based on the fact that the p-values in all models are less than 0.05, indicating that the calculated PP test statistics exceed the critical values for all variables. Therefore, the null hypothesis of a unit root is rejected, and the alternative hypothesis of stationarity is accepted.

Based on the above stationarity results—and in an effort to address the research question regarding the relationship between agricultural technology and sustainable agricultural development in Algeria—it is now appropriate to proceed with a cointegration test using the Bounds testing approach. The Autoregressive Distributed Lag (ARDL) model is particularly suitable for this study's sample size of 32 observations, and aligns well with both economic theory and previous empirical literature.
According to **(Pehlivan & Katirciogl, 2010, p. 1706)** the ARDL methodology is advantageous because it can be applied regardless of whether the variables are integrated at level I(0)I(0)I(0), at first difference I(1)I(1)I(1), or a combination of both. However, it cannot be used if any of the variables are integrated at second difference I(2)I(2)I(2), which is not the case here.

This is further supported by **Pesaran (1997),** who emphasized that the **ARDL** model can be applied as long as the time series under consideration are either level-stationary, first-difference stationary, or a mix of both **(PESARAN, SHIN, & RICHARD, 2001, p. 291)**

The Autoregressive Distributed Lag **(ARDL)** model is estimated over time by formulating the following two models:

$$\Delta GAP_t = \alpha_0 + \alpha_1 GAP_{t-1} + +\alpha_2 am_{t-1} + \alpha_3 aw_{t-1} + \alpha_4 exp.ag_{t-1} + \alpha_6 imp.ag_{t-1} + \sum_{i=1}^{m} \theta_i \Delta GAP_{t-1} + \sum_{i=0}^{n} \theta_i \Delta am_{t-1} + \sum_{i=0}^{n} \theta_i \Delta aw_{t-1} + \sum_{i=0}^{n} \theta_i \Delta exp.ag_{t-1} + \sum_{i=0}^{n} \theta_i \Delta imp.ag_{t-1}$$

3.5.Bounds Test

The Bounds test is conducted to examine the existence of a long-run equilibrium relationship among the variables under study. It is based on testing the null hypothesis that no cointegration exists among the variables in the model, against the alternative hypothesis that a long-run equilibrium relationship does exist. As explained by **(Oteng & Frimpong, 2006, p. 2081)**, the test is structured as follows:

Tab (4): Cointegration Test for the ARDL Model

Test		**Model**	
F-value		4.27	
		The lower bound I(0)	The upper bound I(1)
levels	At 10%	2.253.09	
	At 5%	3.054.22	
	At 1%	4.285.84	
The result		There is a long-term equilibrium relationship at the 0.05 level.	

Source: Prepared by the researchers based on the outputs of Eviews13.

As shown in the table above, the calculated F-statistic value (4.27) exceeds the critical values at both the lower bound (I(0)) and the upper bound (I(1)) at the 5% level of significance. This indicates the rejection of the null hypothesis of no cointegration, confirming the existence of a long-run equilibrium relationship among the variables.

Hence, the variables exhibit a common long-term behavior, and it is appropriate to proceed with the estimation of the Autoregressive Distributed Lag (ARDL) model to analyze both the long-run and short-run dynamics of the relationship.

3.6.Model Quality Test

The table below presents the results of various diagnostic tests used to evaluate the presence of econometric issues and to assess the overall quality of the estimated model.

Tab (5): Diagnostic Tests for the Model

Diagnostic Tests	**Model**	
Breusch-Godfrey (LM)	**Calculated Value**	**Prob**
	0.3987	0.7573
Breusch-Pagan (BP)	0.5139	0.8868
Jarque-bera normality (W)	1.4936	0.4738
Ramsey's RESET	-	-

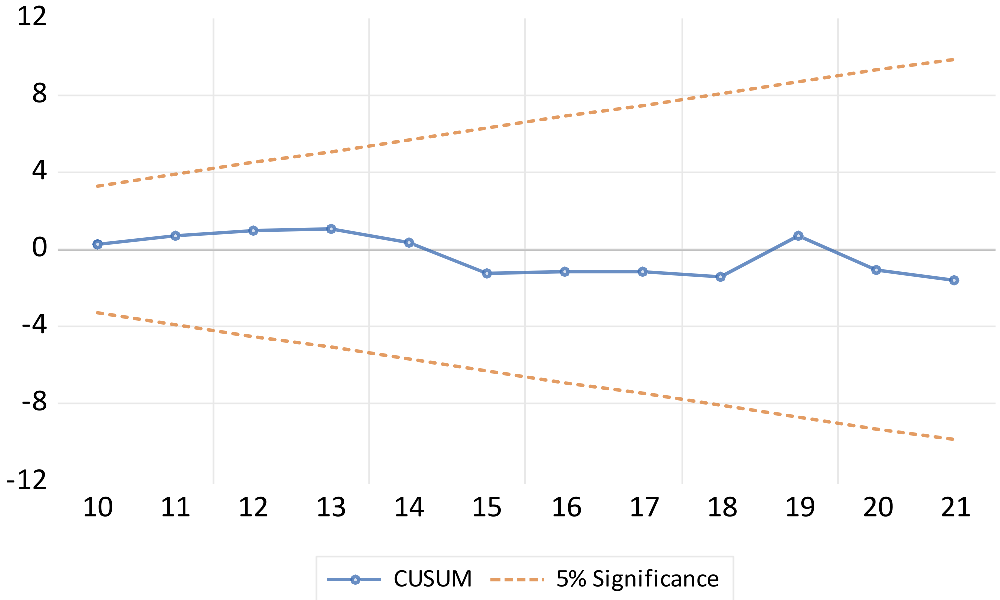
Source: Prepared by the researchers based on the outputs of Eviews13.

According to the results shown in the table above, all p-values exceed the 0.05 significance level, indicating that the model is free from major econometric issues, including autocorrelation, heteroskedasticity, non-normality of residuals, and model misspecification.

3.7.Model Stability Test

The Cumulative Sum (CUSUM) and Cumulative Sum of Squares (CUSUMSQ) tests are used in the second model to verify the absence of structural breaks in the data employed in this study **(Gebrehiwot, 2015, p. 162)**. These tests also help assess the consistency between long-run and short-run coefficients and confirm the appropriateness of the selected lag lengths and degrees of freedom.

Fig (2): Results of the Cumulative Sum of Residuals Test



Source: Eviews13 Software Outputs

Based on the figure above, it is observed that the cumulative sum of residuals forms a central straight line that lies within the confidence bounds at the 5% significance level, indicating the structural stability of the model. This confirms the consistency and alignment between the long-run and short-run results.

3.8.Error Correction Model and Long-term Relationship Shape for the ARDL Model

The following table shows the estimation results for the Autoregressive Distributed Lag **(ARDL)** model. It consists of two parts: the upper part shows the estimation of the Error

Correction Model **(ECM)** and the short-term relationship, while the lower part shows the estimation of the long-term relationship.

Tab (6): ARDL Model Estimation Results

Variables	Coefficients	t-Statistic	Prob
Short-Run Estimation			
Am	-0.049282	-0.4873	0.6348
Exp.ag	-1.009006	0.3313	0.7461
Imp.ag	0.380851	1.1988	0.2537
Aw	6286.609	2.5956	0.0234
CointEP(-1)	-0.570447	-6.0299	0.0000
Long-Run Estimation			
Am	-7010469	-0.32	0.756
Exp.ag	2.47e+9	0.53	0.628
Imp.ag	-1.42e+7	-0.49	0.602
Aw	6.18e+11	0.60	0.557
C	-0.0476651	-0.50	0.0453

Source: Prepared by the researchers based on Stata 17 software.

Table (6) indicates the following:

- Based on the estimation of the error correction model and the long-run relationship, the error correction coefficient is highly significant (p-value = 0.000 < 0.05). This confirms the robustness of the long-run equilibrium relationship, as the model incorporates an effective error correction mechanism. Specifically, 57% of the short-term deviations in sustainable agricultural development (agricultural output) are automatically adjusted toward long-run equilibrium—indicating that short-term errors are corrected within one time period to return to the long-term equilibrium state. Additionally, agricultural imports and land area have a positive short-run impact on agricultural output. This suggests that a one-unit increase in agricultural imports and land area leads to an increase of **0.38** and **6,286.906**, respectively, in agricultural output.

As for the coefficients of the other variables, they are negative and statistically insignificant, indicating an inverse relationship between these variables and agricultural output. This finding contradicts economic theory.

- Based on the estimation of the long-run relationship, the estimated equation is as follows:

$$\boldsymbol{gap = -0.047 - 7010469AM + 2.47exp.ag - 1.42Imp.ag + 6.18Aw}$$

It can be observed from the above equation that the relationship between the variable *gap* and itself is negative. Additionally, the coefficients for both agricultural exports and agricultural land area are positive but statistically insignificant, which explains that an increase in agricultural exports leads to an increase in income sources, thus contributing to higher GDP and an increase in the relative importance of agricultural output (indicating expansion). Similarly, an increase in agricultural land area leads to higher agricultural production and productivity. As for the coefficients of the remaining variables, they are negative and insignificant, and these results are consistent with economic theory.

The key findings derived from the model estimation show a general consistency between the short-run and long-run dynamics. The results indicate that the impact of technological and technical variables on agricultural output in the Algerian economy is positive in both the short and long term, aligning with theoretical expectations regarding the relationship between these variables. This outcome can be interpreted through two main mechanisms: first, fluctuations in the study variables—whether increases or decreases—may lead to setbacks in agricultural output. Second, the decline in agricultural output may also stem from changes in variables such as agricultural imports and mechanization, which are largely linked to limited funding and the lack of scientific expertise and technical skills in managing agricultural projects and machinery.

Increased mechanization implies a rise in demand for agricultural output that is not matched by technical improvements in agriculture, particularly in the short term, relative to the long run. This is evidenced by the estimated elasticities or partial coefficients. Moreover, the results suggest that agricultural exports serve as a key driver of agricultural output in the short term. In the long run, however, other factors may intervene, limiting the effect of technical and technological agricultural variables, which explains the relatively weak long-run relationship. In this context, the government can adopt monetary, fiscal, and agricultural policies to boost the acquisition of agricultural machinery, integrate advanced technologies into the agricultural sector, and increase financial support for landowners and rural communities. Efforts should also focus on raising awareness and enhancing the skills of young workers.

Recent studies have shown that agricultural exports can stimulate agricultural output and generate substantial economic growth by increasing foreign exchange revenues, creating employment opportunities, and improving food security **(El Weriemmi & Bakari, 2024)**. Additionally, long-term responses in agricultural output may be affected by other structural or environmental factors.

Ultimately, Algeria has made considerable efforts to enhance and valorize its agricultural sector as part of a broader food security strategy by implementing a set of comprehensive measures and policies. One notable initiative is the Agricultural Model 2020–2024, which aims to strengthen sustainability in the secto **(Bouchenafa, 2025)** r. This model has achieved promising results compared to previous periods. However, its long-term sustainability remains uncertain due to the substantial effects of climate change on agricultural output, which continues to pose serious risks to agricultural resources and production branches, leading to a potential decline in overall agricultural performance.

4. Conclusion

The agricultural sector is considered one of the most important sectors in diversifying the national economy and serves as an alternative to the oil sector, especially given the failure of governments to reduce dependency on oil. It is also the cornerstone of the national economy and a starting point for stimulating other economic sectors through a set of measures aimed at achieving food security, which helps maintain balance and alignment between various sectors.On the other hand, stimulating agricultural production is essential to meet the growing demands of individuals due to the increasing population growth. All of this aims to achieve sustainable agricultural development within the broader framework of economic development. To achieve this, there is an urgent need to diversify the agricultural sector, meaning increasing the variables and factors that influence this sector.

Therefore, it can be said that agricultural development is one of the most important indicators that can help a country rise in a short period, due to the reliance on technological and technical advancements in the agricultural sector, as well as the utilization of scientific research personnel to serve and enhance agriculture. This, in turn, aims to achieve both economic and social development with the ultimate goal of improving the standard of living. Especially in the Algerian rural areas, which suffer from significant marginalization that negatively impacts the development of the national economy. This can be addressed by focusing on preserving natural resources and improving the efficiency of their use. Empowering farmers to utilize technology in agriculture can improve efficiency, while also enabling them to better cope with crises and environmental disasters that occur at certain times.

Based on the above, a number of conclusions have been drawn, which can be summarized in the following points:

- The Algerian economy is primarily an oil-based economy, which has undergone many fluctuations closely linked to oil price volatility during the study period. The agricultural sector, however, was the one that remained unaffected by the recent **COVID-19** pandemic.
- The selected economic and technical factors gained significant attention due to farmers' focus on developing and improving the agricultural sector to increase productivity within the framework of achieving food security. Agricultural output saw an increase throughout the study period, with a slight improvement during the 1990s, attributed to the economic policies implemented by the government at that time.
- There is a correlation between total agricultural output and the mentioned variables, except for the food gap, which is negatively correlated with agricultural output. This is consistent with economic theory.
- From a statistical perspective, the time series under study are integrated of the first degree and at the same level, which allows for the application of the Autoregressive Distributed Lag **(ARDL)** methodology. A linear relationship was found between the variables under study, and the results of the **Bounds Test** for cointegration indicated the existence of a long-run equilibrium relationship between the variables and agricultural output.
- According to the error correction coefficient, which is equal to -0.52, the period required for returning from the long run to the short run equilibrium is approximately two years (1.92). This is a short period, indicating a rapid return to

equilibrium compared to the significance of agricultural output changes and its fluctuations on economic activity and its impact on other sectors. Therefore, the system tends to return to equilibrium, meaning that in the event of any disruption, the model will return to equilibrium within approximately two years.

- There is a symmetrical effect of economic and technical factors on sustainable agricultural development in Algeria during the period from 1991 to 2023.
- Among the most important economic factors are agricultural output, the workforce, GDP, investment expenditure, and increased production aimed at bridging the food gap, in addition to the technical factors, which include technology, scientific research, and support for extension services. These factors collectively influence sustainable agricultural development (a proven hypothesis).

Based on the previous results, several recommendations can be made, including:

- Diversifying sources of income and productivity to increase agricultural GDP, thereby contributing to the improvement of the economy.
- Focusing on agricultural research and technology.
- Adopting agricultural policies and encouraging agricultural investments to provide job opportunities and reduce unemployment rates.
- Preserving the stock of food commodities and developing strategies to increase exports by strengthening efforts towards the agricultural sector within the framework of achieved economic development.
- Integrating agricultural technology that is capable of enhancing productive efficiency.
- Drawing on the experience of technologically advanced countries by adopting innovative agricultural practices, including the introduction of new cultivation methods such as hydroponics.

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