

## Agricultural Value Added in Pakistan: Roles of FDI, Technological Innovation, Employment, and Renewable Energy Consumption



Khawaja Asif Mehmood <sup>a</sup> Fareeha Riaz <sup>b</sup> Farzana Munir <sup>c</sup>

**Abstract:** *Agriculture value added is a key aspect for agrarian economies like Pakistan. This research examines the state of agriculture value added in the presence of Foreign Direct Investment (FDI), technological innovation, employment in the agriculture sector, and usage of renewable energy. The data was collected from 1990 to 2025. The analysis is done by using Autoregressive Distributed Lag (ARDL). The results confirm that FDI and technological innovation positively affect agriculture value added in Pakistan. Of renewable energy, the results are surprisingly negative. The policy option is to ensure a consistent flow of FDI and a productive usage of technology for better agricultural productivity.*

**Keywords:** Agriculture Value Added, Technological Innovation, FDI, Regulatory Quality, ARDL, Pakistan

### Introduction

On the Asian front, the agriculture sector does play a significant role in food security (Montesclaros & Teng, 2021). Despite a reduced agricultural contribution to the Asian GDP by 13 percent (World Bank, 2020), agriculture is an essential economic activity in a region and a dominant source of employment in rural areas. According to Montesclaros and Teng (2021), 60 percent of the world's population that lives in Asia, the 81 percent relies upon the agriculture sector for its livelihood. Food security, economic growth, employment, and sustainable development, according to Shah et al. (2024), depend upon agricultural value addition, particularly in Asian economies. On the other hand, agrarian production degrades the resources and also contributes to greenhouse gas emissions, thereby driving global warming. The technological innovation is recognized as a crucial factor in tackling the climate-related challenges. The digital technologies like remote sensing, artificial intelligence, and precision agriculture cultivation techniques, along with the advanced biotechnology and renewable energy, provide the solution towards the optimum resource usage together with the development of climate-resilient crops and a noticeable reduction in greenhouse gas emission (Venturini, 2025).

FDI plays a vital role in enhancing productivity and the introduction of advanced technologies in order to improve the agriculture-related infrastructure. In the context of food demand, the proper utilization of FDI capital is crucial to favor agricultural productivity across a wider spectrum. Since FDI favored firms are largely export-oriented, directing their capital into high-tech agricultural ventures can amplify both the volume and market value of farm exports, thereby strengthening the sector's international competitiveness.

Academic perspectives on this impact remain divided. Research by Rahman et al. (2024) indicates that FDI inflows play a statistically significant role in expanding agriculture's contribution to total GDP, leading to recommendations for more aggressive government incentives to attract foreign investors. Conversely, Sultana and Sadekin (2023) observed a negative correlation between FDI and domestic agricultural health. Their findings suggest that capital alone is insufficient; they argue that the state must prioritize human capital development—specifically through farmer training and skill enhancement—to ensure that foreign investment actually translates into higher productivity rather than displacing local industry.

<sup>a</sup> Assistant Professor of Economics, School of Economics, Bahauddin Zakariya University, Multan, Punjab, Pakistan.

<sup>b</sup> Assistant Professor, Department of Management Science, National University of Modern Languages, Islamabad, Pakistan.

<sup>c</sup> Assistant Professor, School of Economics, Bahauddin Zakariya University, Multan, Punjab, Pakistan.

The agriculture sector of Pakistan contributes around 23 percent to the GDP and provides employment opportunities for around 37.4 percent of the national labor force. The United Nations' Food and Agriculture Organization (2026) confirms that about 70 percent of Pakistan's exports are derived from the agriculture sector. Covering an area of above 30 million hectares, 47 percent of the national land is agri-based, which is greater than the global average of 38 percent. In the agriculture sector, livestock has an irresistible involvement of 62 percent, followed by central crops (4.1 percent), other crops (3.3 percent), fisheries (0.3 percent), and forestry (0.5 percent).

Pakistan has two major seasons of cropping, which are Kharif and Rabi. The total water availability is for 72.7-million -acre feet. More than 18 percent is rainfed, and 82 percent of cultivated land is irrigated. 60 percent of the rainfed land is used for winter-season crops. Wheat and rice are staple food crops. Major cash crops are Sugarcane and cotton. Pakistan has an estimated population of livestock of 225 million, with a recorded value addition of PKR 5.5 trillion in 2023. Pakistan is the 5th largest milk producer in Asia. Due to a vast population of livestock, Pakistan fetches USD 950 million in exports of leather and is thus the 4th largest leather apparel exporter in Asia.

This study contributes to the literature by several key objectives that enable exploring the significance of employment in agriculture, which contributes to the agriculture value added of Pakistan. Moreover, the key aspects such as technological innovation, FDI, and renewable energy consumption are also traced for their profound effects on the agricultural productivity of Pakistan.

The remainder of the study is arranged in a way that Section II precisely reviews the Literature. Methodological Framework is given in Section III. Whereas Sections IV and V are allocated for the Results and Discussions, and the Conclusion and Policy Recommendations.

## Literature Review

The recent research on agriculture value added and productivity emphasizes the transition from the traditional to the data-centric paradigms in view of analyzing the impacts of macroeconomic shift and climate change.

Researchers have indicated that economic globalization, via the channels of fertilizer intake and FDI, significantly influences the agriculture value added (Sansika et al., 2023). In this regard, green finance has also emerged as a crucial driving factor to improve the agricultural value added by the practices of sustainable development-based funding for agricultural productivity (Epor & Akande, 2025).

The adoption of Edge AI and Tiny Machine Learning is also being researched as an option to enhance agricultural productivity by reducing latency and costs (Samanta & Saha, 2026). Digitalization is indeed framed as a game changer in the way of producing more with the lowest environmental hazards, though its on-ground actual impact remains dependent on the context of its usage and adoption (Manta, 2026).

The recent time series-based empirical findings showed a nonlinear, inverted U-shaped relationship between agricultural productivity and temperature, thus indicating that beyond optimal temperature benchmarks, agricultural productivity is impacted negatively due to unexpected weather conditions (Padda, 2026).

Analytics such as Sansika et al. (2023), Sinha (2024), Epor (2025), Padda (2026), and Cloete et al. (2025) distinguished with the macroeconomic variables, green finance, climate change, infrastructure energy, and globalization and FDI on the agriculture value addition, employment, and productivity. For instance, FDI and agricultural employment are found to positively impact the agricultural value added globally across varied income levels (Sansika et al., 2023). Trade openness and economic growth are related in the long term with the agriculture value addition and productivity (Sinha, 2024). Moreover, Epor and Akande (2025) found that mitigated green finance and financial inclusion have been proven to boost agricultural productivity. Nevertheless, Padda (2026) explored that rising temperatures and rainfall deficits cause severe losses in the

agricultural value addition. The power shortages and outages (load shedding) disrupt the agricultural productivity and cause a significant reduction in the agricultural value addition of specific sectors like fruit and farming (Cloete et al., 2025).

The examined literature indicates that FDI holds a positive but complex relationship with agricultural productivity. In Tanzania, studies revealed that while FDI positively influences agricultural value added, the impact is statistically insignificant, thus suggesting that the alignment and scale of FDI with local needs are inadequate for substantial growth (Sanguila et al., 2025). Similarly, empirical analysis showed no significant effect of FDI inflows on agriculture's contribution to GDP, notwithstanding increasing FDI levels, implying inefficiencies within the sector and limited direct paybacks from FDI in furthering the productivity (Epaphra & Mwakalasya, 2017). Conversely, broader analyses highlighted that FDI enhances agricultural productivity and export capacity in African agriculture when it is combined with efforts to improve land use and infrastructure (Gunasekera et al., 2015). In the Indian context, analytics viewed FDI as a catalyst for technological advancement, productivity improvements, and employment creation, although the sectoral growth remains dependent on effective policy implementation and sector-specific strategies (Gopalakrishna, 2019). Overall, the empirical evidence suggests that FDI has the potential to improve agricultural productivity, but the effectiveness of FDI inflows hinges on the non-addressing of infrastructural, targeted policies, sector-specific investments, and institutional constraints. The literature underscores that deprived of strategic alignment and loyal policies, the impact of FDI on agricultural productivity remains partial, despite its documented benefits in technology transfer and resource mobilization.

A novel approach to judging energy utilization in agriculture includes calculating the value of produced output per unit of energy input, which enables comparisons across regions, systems, and over time. Doing it that way aids in policy formulation and identifying comparative advantages (Singh, 1993). This measure aligns with wider energy efficiency concepts that are often proxied by an energy intensity—defined as energy consumption per unit of production—used to observe the developments in energy efficiency over time, although it may be influenced by factors beyond efficiency alone (United States Office of Energy Markets and End Use. (1991). In manufacturing, energy intensity serves as a surrogate for energy efficiency, with reductions indicating potential efficiency gains; however, it is also subject to external influences such as market conditions (United States Office of Energy Markets and End Use. (1991). Additionally, energy efficiency policies also generate manifold benefits beyond energy savings, including economic growth, environmental sustainability, and social wellbeing, which strengthen the reputation of a wide-ranging evaluation framework (International Energy Agency, 2014). Louisiana's renewable energy initiatives exemplify how regional strategies can expand energy sources and endorse sustainable development, aligning with the broader goals of favoring energy productivity and efficiency in agriculture and industry (Louisiana, 2013). Overall, integrating measures of energy productivity with assessments of manifold benefits can bring sustenance towards effective policies aimed at improving the energy utilization in the manufacturing and agriculture sectors.

Technological innovation also adds to the value addition in agriculture. Yang et al. (2024) and Huang and Ping (2025) signified that technological innovations engage sustainable development in agricultural productivity. In this regard, the adoption of technological innovations that are agriculture-specific contributes to addressing the climate challenges and price volatilities.

## **Methodological Framework**

This study computes the relationship between FDI, technological innovation, employment, and renewable energy consumption on the agriculture value added of Pakistan. The chosen time period is from 1990 to 2025. The time series data is gathered from The World Bank Development Indicators. Table 1 represents measurements of the variable. Figure 1 highlights the stages of empirical analyses.

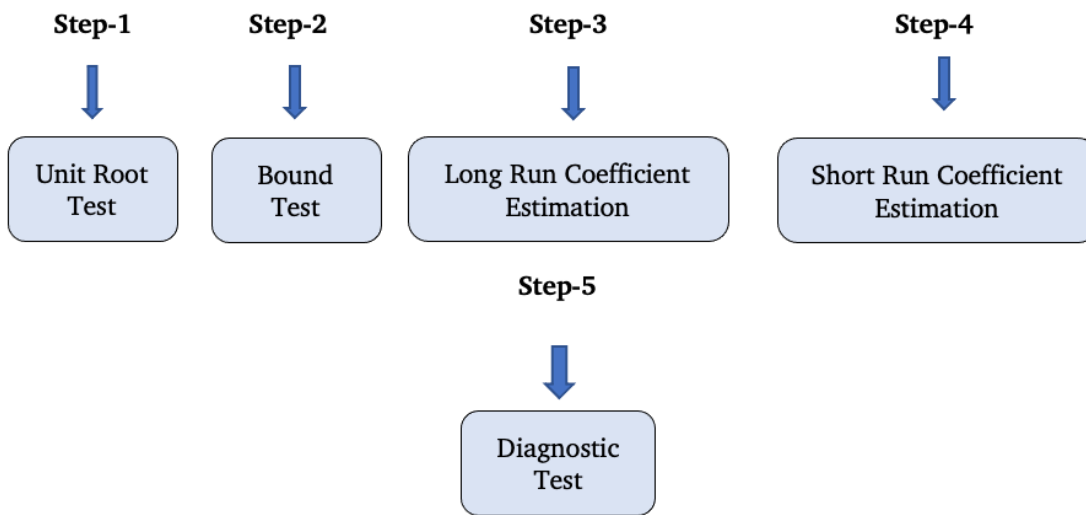
**Table 1**

*Variable's Description*

Variables	Symbols	Measurement
Agriculture Value Added (Million \$)	AGR	Agriculture, forestry, and fishing correspond to ISIC (Rev. 4) divisions 01-03 and include the exploitation of vegetal and animal natural resources, comprising the activities of growing crops, raising and breeding animals, harvesting of timber and other plants, animals, or animal products from a farm or their natural habitats. Value added is the contribution to the economy by a producer, an industry, or an institutional sector, which is estimated by the total value of output produced and deducting the total value of intermediate consumption of goods and services used to produce that output. This indicator is expressed in current prices, meaning no adjustment has been made to account for price changes over time."
Foreign Direct Investment (Million \$)	FDI	Foreign direct investment is a category of cross-border investment associated with a resident in one economy having control or a significant degree of influence on the management of an enterprise that is resident in another economy. Ownership of 10 percent or more of the voting power is evidence of a direct investment relationship. This indicator is expressed in current prices, meaning no adjustment has been made to account for price changes over time."
Technological Innovation	TCI	"Patent applications are worldwide patent applications filed through the Patent Cooperation Treaty procedure or with a national patent office for exclusive rights for an invention--a product or process that provides a new way of doing something or offers a new technical solution to a problem. A patent provides protection for the invention to the owner of the patent for a limited period, generally 20 years."
Employment (In Percentage)	EMP	"Employment is defined as persons of working age who were engaged in any activity to produce goods or provide services for pay or profit, whether at work during the reference period or not at work due to temporary absence from a job, or to a working-time arrangement. The agriculture sector consists of activities in agriculture, hunting, forestry, and fishing, in accordance with division 1 (ISIC 2) or categories A-B (ISIC 3) or category A (ISIC 4)."
Energy Consumption	ENC	"Renewable energy consumption is the share of renewable energy in total final energy consumption."

Figure 1 highlights the stages of empirical analyses that are based upon the Autoregressive Distributed Lag (ARDL).

**Figure 1**  
Stages of Empirical Analyses



The econometric model of the research is specified below;

$$AGR_t = \beta_0 FDI_t + \beta_1 TCI_t + \beta_2 EMP_t + \beta_3 ENC_t + \mu_t \quad [1]$$

Where AGR denotes agriculture value added. FDI is a foreign direct investment. TCI indicates technological innovation. EMP is a notation of employment in the agriculture sector. And ENC is a donation of renewable energy consumption. The  $\mu_t$  is the error term.

This research evaluates the presence of a long-run relationship between agriculture value added and FDI, TCI, Emp, and ENC by utilizing the ARDL technique of cointegration. Based on this objective, the model is stated as follows;

$$\Delta AGR_{t-1} = \partial_0 + \partial_1 FDI_{t-1} + \partial_2 TCI_{t-1} + \partial_3 EMP_{t-1} + \partial_4 ENC_{t-1} + \sum_{i=1}^p \phi_1 AGR_{t-i} + \sum_{i=1}^p \phi_2 FDI_{t-i} + \sum_{i=1}^p \phi_3 TCI_{t-i} + \sum_{i=1}^p \phi_4 EMP_{t-i} + \sum_{i=1}^p \phi_5 ENC_{t-i} + \mu_t \quad [2]$$

The  $\Delta$  represents the first difference based on Akaike Information Criteria. The optimal lag option is shown by  $t-1$ . The  $\Delta$  an  $\phi$  analysis of long-term cointegration. The  $H_0$  and  $H_1$  hypotheses are of the Bound Test, based on the following expressions;

$$H_0 = \partial_1 = \partial_2 = \partial_3 = \partial_4 = 0$$

$$H_1 \neq \partial_1 \neq \partial_2 \neq \partial_3 \neq \partial_4 \neq 0$$

Following Pesaran et al. (2001), the long-run relationship exists if the computed F-statistic is greater than the upper bound threshold, and conversely, it is true. The result is inconclusive if the F-statistic lies between the lower and upper bound threshold boundaries.

The ARDL model is employed when the regressors are integrated of order I(0) and I(1). The long run coefficients are found by the means of the following equation;

$$\Delta AGR_t = \partial_0 + \sum_{i=1}^p \phi_1 AGR_{t-i} + \sum_{i=1}^p \phi_2 FDI_{t-i} + \sum_{i=1}^p \phi_3 TCI_{t-i} + \sum_{i=1}^p \phi_4 EMP_{t-i} + \sum_{i=1}^p \phi_5 ENC_{t-i} + \mu_t \quad [3]$$

This  $\phi$  denotes the long-run coefficient.

The error correction model for the short-run ARDL model is given below;

$$\Delta AGR_t = \partial_0 + \sum_{i=1}^p \delta_1 AGR_{t-i} + \sum_{i=1}^p \delta_2 FDI_{t-i} + \sum_{i=1}^p \delta_3 TCI_{t-i} + \sum_{i=1}^p \delta_4 EMP_{t-i} + \sum_{i=1}^p \delta_5 ENC_{t-i} + \gamma ECT_{t-1} + \mu_t \quad [4]$$

The  $\delta$  is the short-run coefficient of the regressors, and  $\gamma$  is the coefficient of the Error Correction Term (ECT), which illustrates the speed with which the system gets back to the original equilibrium after the shock. The computed coefficient of ECT has to be significant and negative in sign.

### Results and Discussion

The descriptive statistics results are given in Table 2. Findings show that wider dispersions are evident in all the variables. Mixed results are found in the case of skewness. FDI is found platykurtic. Jarque-Bera makes a clear observation that the majority of the selected variables are normally distributed.

**Table 2**  
*Descriptive Statistics*

	AGR	FDI	TCI	EMP	ENC
Mean	43438.14	-1561.48	861.56	40.62	48.39
Minimum	9229.23	-5492.00	502.00	36.23	41.60
Std. Dev.	26833.13	1327.03	300.91	2.24	4.40
Skewness	0.25	-1.45	0.71	-0.66	0.47
Kurtosis	1.58	5.00	2.67	2.19	2.40
Jarque-Bera	3.41	18.68	3.21	3.58	1.87
Probability	0.18	0.00	0.20	0.17	0.39

The correlation results are presented in Table 3. All the variables are negatively correlated with the regressand and are moderately correlated. However, ENC is found to be significant in correlation with the AGR.

**Table 3**  
*Correlation*

	AGR	FDI	TCI	EMP	ENC
AGR	1.00				
FDI	-0.38	1.00			
TCI	-0.32	-0.43	1.00		
EMP	-0.49	-0.14	0.47	1.00	
ENC	-0.88	0.58	0.01	0.32	1.00

Moving towards the empirical results, the unit root test is given in Table 4. The conclusion is drawn in a way that mixed order of integration is found on the selected variable; thus, ARDL is considered a viable regression technique to compute the regression analyses.

**Table 4**  
*Unit Root Test*

Variable	Constant	First Difference	Conclusion
AGR	-3.65	-6.55*	I(1)
FDI	-2.70*	--	I(0)
TCI	-3.63	-4.79*	I(1)
EMP	-1.18	-8.24*	I(1)
ENC	-2.01	-6.04*	I(1)

Table 5 clarifies that the  $H_0$  of no long-run relationship is rejected. The bond between the AGR and selected variables does exist in the long run. The value of the computed F-statistic is greater than the upper bound critical value. Therefore, it is concluded that FDI, TCI, EMPL, and ENC are cointegrated with AGR.

**Table 5**

*Bound Test*

Model	F-Statistics	Upper Bound Critical Value	Conclusion
Model I $AGR = f(FDI, TCI, EMP, ENC)$	11.65	4.37	Co-integration exist

Long-run coefficient estimates are given in Table 6. FDI possesses positive effects on AGR. By accelerating agricultural productivity through injecting modern capital, technology, and a strong organizational structure, FDI improves farming. The results move in line with Joseph (2025) and Wabwile et al. (2024). Technological innovations also have positive effects on agricultural productivity since they affect the farmers' wellbeing and productivity. The results of this research also indicate a positive relationship between the two. Efficient use of resources, especially by small farmers, support of education, and access to credible education add to the value addition in agriculture (Danda, 2023; Dimitrova, 2022; Bagri, 2024; Andrianarison, 2022). The variable of employment based on agriculture is found to be insignificant. However, it is significant to note that the impact of renewable energy usage is found to be significant but negative in relation to AGR. But it is not hard to recall that in the absence of strong government policies and high regulatory quality, the effect of the transition of renewable energy inadvertently disrupts agricultural productivity, akin to Wang et al. (2023). The issue itself stems from the institutional failure to merge and manage the transition properly. Land use conflicts sway away the fruits of renewable energy when improper zoning laws promote private developers to turn fertile agricultural land into residential societies, which are expected to favor society in the far future, leaving behind the readily positive effects of agricultural farming towards the general public in the shape of covering the food needs. Therefore, unstable energy failure, institutional gaps, and weak incentives for the agro-renewables cause the same issues that are found in this research, as far as the ENC and AGR are concerned. Findings are referred to Situma (2025).

**Table 6**

*Estimates of Long-run Coefficients*

Variable	Coefficient	Std. Error	t- Ratio	Prob.
FDI	21.47	10.19	2.11	0.01
TCI	56.56	28.90	1.96	0.07
EMP	6800.35	5286.83	1.29	0.22
ENC	-8132.11	2712.40	-3.00	0.01
C	216345.76	127572.48	1.70	0.11

The short-run coefficient estimates are presented in Table 7. Mixed results are fetched in most cases of the variables. However, the results of TCI are consistent with those found in the long-run case. Therefore, the technological innovations are crucial for value addition in agriculture. In the case of renewable energy consumption, the outcomes do not mitigate the positive relationship with the agriculture productivity, precisely at two- and three-year lag. The coefficient of the error term is found to be significant and correctly signed. Thereby, indicate the reversal towards the long-run equilibrium at 11 percent.

The study also passes the diagnostics of serial correlation, heteroskedasticity, residuals' normality, and the correct model specification.

**Table 7**

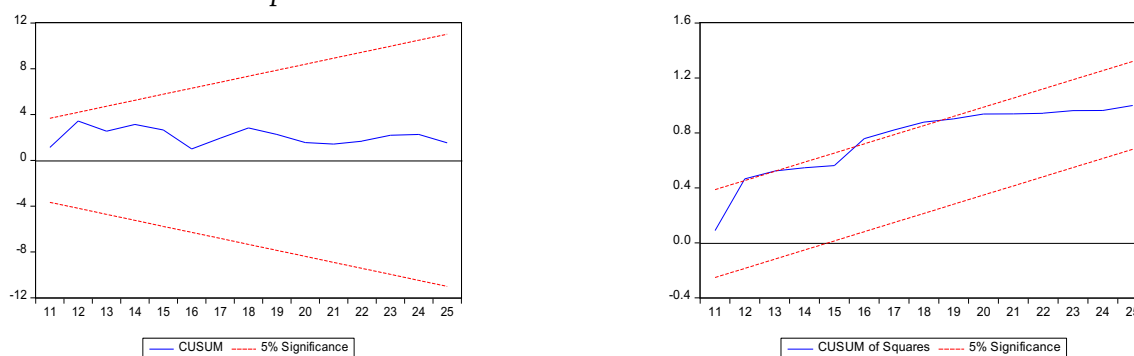
*Estimates of Short-run Coefficients*

Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(FDI)	-0.38	0.50	-0.76	0.46
D(FDI(-1))	1.15	0.41	2.83	0.01
D(FDI(-2))	3.32	0.38	8.70	0.00
D(TCI)	6.22	2.78	2.23	0.04
D(EMP)	-1231.96	278.79	-4.42	0.00
D(EMP(-1))	874.67	272.34	3.21	0.01
D(EMP(-2))	1403.27	265.73	5.28	0.00
D(EMP(-3))	-508.56	291.44	-1.75	0.10
D(ENC)	-402.68	242.00	-1.66	0.12
D(ENC(-1))	-1964.54	243.53	-8.07	0.00
D(ENC(-2))	518.17	256.62	2.02	0.06
D(ENC(-3))	1306.83	266.72	4.90	0.00
ECT	-0.11	0.01	-10.13	0.00
Diagnostic Test (F-statistics with prob. in parentheses)				
LM Test of Serial Correlation				9.9 (0.12)
Breusch-Pagan-Godfrey Heteroskedasticity Test				0.42 (0.95)
Jaque-Bera Test of Normality				0.95(0.62)
Ramsey RESET Test				0.51(0.48)

The structural stability test of CUSUM and CUSUM Sq is given in Figure 2. It reflects the stability of the model variance.

**Figure 2**

*CUSUM and CUSUM Sq.*



**Conclusion and Policy Recommendation**

Agricultural productivity is essential for the agrarian economies that rely upon it for their economic growth targets. This research looked into the value added in agriculture against the core variables such as FDI, technological innovation, employment, and renewable energy consumption. The Bound Test results confirmed the long-run cointegration. However, long run and short run coefficients were found to have different states of being. In the case of the long run, FDI and TCI were found to positively affect agriculture value added. Whereas, it is shocking to note that renewable energy consumption was found to negatively effect agriculture value added during the selected time span from 1990 to 2025. This outcome reflects the weak regulatory quality which infringes the positive cast over of ENC over AGR.

As a policy recommendation, the government and the other stakeholders need to strengthen the vision of favoring agriculture productivity through use of technology and FDI. Government is considered to take measures for analyzing these outcomes in relation with regulatory quality to observe better functioning of the agriculture sector.

## References

- Andrianarison, F., Kamdem, C. B., & Che Kameni, B. (2022). Factors enhancing agricultural productivity under innovation technology: Insights from Cameroon. *African Journal of Science Technology Innovation and Development*, 14(5), 1173–1183. <https://doi.org/10.1080/20421338.2021.1937816>
- Bagri, P. (2024). Agricultural innovation: The impact of modern technologies. *ShodhKosh: Journal of Visual and Performing Arts*, 5(5). <https://doi.org/10.29121/shodhkosh.v5.i5.2024.2749>
- Cloete, K., Davids, T., Merwe, M. van der, Meyer, F., & Pienaar, L. (2025). Case in point: estimating the impact of loadshedding on the Western Cape agricultural sector. *Agrekon*, 64(3–4), 432–451. <https://doi.org/10.1080/03031853.2025.2584218>
- Danda, R. R. (2023). Innovations in agricultural machinery: Assessing the impact of advanced technologies on farm efficiency. *Journal of Artificial Intelligence and Big Data*, 3(1), 29–48. <https://doi.org/10.31586/jaibd.2023.1156>
- Dimitrova, A. (2022). Technological innovations in agriculture as a way to increase food security. *Economic Thought Journal*, 6(6), 692–704. <https://doi.org/10.56497/etj2267604>
- Epaphra, M., & Mwakalasya, A. H. (2017). Analysis of foreign direct investment, agricultural sector and economic growth in Tanzania. *Modern Economy*, 08(01), 111–140. <https://doi.org/10.4236/me.2017.81008>
- Epor, S. O., & Akande, J. O. (2025). Sustainable development in emerging economies: Comparing the impacts of green finance and financial inclusion. *Modern Finance*, 3(4), 1–21. <https://doi.org/10.61351/mf.v3i4.259>
- Gopalakrishna M, D. G. (2019). Foreign Direct Investment and Indian agriculture: Its pros and cons. *EPRA International Journal of Agriculture and Rural Economic Research*, 15–17. <https://doi.org/10.36713/epra2704>
- Gunasekera, D., Cai, Y., & Newth, D. (2015). Effects of foreign direct investment in African agriculture. *China Agricultural Economic Review*, 7(2), 167–184. <https://doi.org/10.1108/caer-08-2014-0080>
- Huang, L., & Ping, Y. (2024). The impact of technological innovation on agricultural green total factor productivity: The mediating role of environmental regulation in China. *Sustainability*, 16(10), 4035. <https://doi.org/10.3390/su16104035>
- International Energy Agency. (2014). Capturing the multiple benefits of energy efficiency. Report (Brochure). Available at: <http://www.iea.org/termsandconditionsuseandcopyright/>
- Joseph, J. (2025). Examining foreign direct investment effects on agricultural productivity in Sub-Saharan African economies. *International Economics*, 184(2025), 1-15.
- Louisiana. (2013). Louisiana's clean energy resources and economy (Brochure), report, March 1; Golden, Colorado. Available at: <https://digital.library.unt.edu/ark:/67531/metadc832099/>:
- Manta, A. G. (2026). From sustainability narratives to digital infrastructures: Mapping the transformation of smart agri-food systems. *Foods (Basel, Switzerland)*, 15(3), 469. <https://doi.org/10.3390/foods15030469>
- Montesclaros, J. M. L., & Teng, P. S. (2021). Agriculture and food security in Asia. In *Climate change, disaster risks, and human security: Asian experience and perspectives* (pp. 137-168). Singapore: Springer Singapore.
- Padda, I. U. H. (2026). Investigating the long-term and short-term effects of climate change on agricultural productivity: Evidence from Pakistan. *Social Science Review Archives*, 3(4), 2410-2429.
- Rahman, M. C., Rahaman, M. S., Sarkar, M. A. R., & Islam, M. A. (2024). Foreign direct investment and agricultural output nexus in Bangladesh: An autoregressive distributed lag approach. *Journal of Agriculture and Food Research*, 15(101042), 101042. <https://doi.org/10.1016/j.jafr.2024.101042>
- Samanta, R., & Saha, B. (2026). Affordable precision agriculture: A deployment-oriented review of low-cost, low-power Edge AI and TinyML for resource-constrained farming systems. In *arXiv [cs.ET]*. <https://doi.org/10.48550/arXiv.2603.15085>

- Sangulla, L. J., George, W., & Mwinuka, L. (2025). Foreign direct investment and the agriculture sector performance in Tanzania: an autoregressive distributed lag approach. *Cogent Food & Agriculture*, 11(1). <https://doi.org/10.1080/23311932.2025.2515489>
- Sansika, N., Sandumini, R., Kariyawasam, C., Bandara, T., Wisenthige, K., & Jayathilaka, R. (2023). Impact of economic globalisation on value-added agriculture, globally. *PLOS ONE*, 18(7), 1-17. <https://doi.org/10.1371/journal.pone.0289128>
- Shah, W. U. H., Lu, Y., Liu, J., Rehman, A., & Yasmeen, R. (2024). The impact of climate change and production technology heterogeneity on China's agricultural total factor productivity and production efficiency. *The Science of the Total Environment*, 907(168027), 168027. <https://doi.org/10.1016/j.scitotenv.2023.168027>
- Singh, A. (1993). Measurement of energy use in agriculture. *Outlook on Agriculture*, 22(2), 119–121. <https://doi.org/10.1177/003072709302200210>
- Sinha, J. K. (2024). Assessing GVA contributions, FDI impact, economic growth and trade openness on agricultural productivity in India: An ARDL approach. *Digital Journal of Science*, 2(3), 124–142.
- Situma, M. P. (2025). Powering sustainable agricultural growth: The impact of renewable energy consumption on Kenya's agriculture sector. *International Journal of Research and Scientific Innovation*, 12(10), 3424–3436. <https://doi.org/10.51244/ijrsi.2025.1210000297>
- Sultana, Z., & Sadekin, M. N. (2023). The impact of FDI on the agriculture sector: A case study from Bangladesh. *Heliyon*, 9(12), e22983. <https://doi.org/10.1016/j.heliyon.2023.e22983>
- United States Office of Energy Markets and End Use. (1991). *Changes in energy intensity in the manufacturing sector*. Energy Information Administration, Energy Markets and End Use. <https://purl.fdlp.gov/GPO/LPS28838>
- Venturini, R. E. (2025). Technological innovations in agriculture: the application of Blockchain and Artificial Intelligence for grain traceability and protection. *Brazilian Journal of Development*, 11(3), e78100. <https://doi.org/10.34117/bjdv11n3-007>
- Wabwile, I., Ali, U. A., Simiyu, E. J., & Ngala, C. (2024). foreign direct investment and its effect on agricultural productivity Kenya. *International Journal of Finance & Banking Studies*, 13(4), 48–57. <https://doi.org/10.20525/ijfbs.v13i4.3736>
- Wang, J., Jiang, C., Li, M., Zhang, S., & Zhang, X. (2023). Renewable energy, agriculture, and carbon dioxide emissions nexus: implications for sustainable development in sub-Saharan African countries. *Sustainable Environment Research*, 33(1). <https://doi.org/10.1186/s42834-023-00193-8>
- Yang, F., Ibrahim, R. L., Ajide, K. B., & Al-Faryan, M. A. S. (2024). Examining the ecological effects of energy transition, environmental technology, and structural change in BRICS economies: implications for sustainable development. *Energy Sources, Part B: Economics, Planning, and Policy*. 19(1), 1-20. <https://doi.org/10.1080/15567249.2024.2419956>