International Journal of Energy Economics and Policy

ISSN: 2146-4553

available at http: www.econjournals.com

International Journal of Energy Economics and Policy, 2026, 16(2), 205-213.

The Role of Green Economy in the Sustainable Development of Agro-Industrial Complex: Evidence from Uzbekistan

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Received: 10 August 2025 **Accepted:** 03 January 2026 **DOI:** https://doi.org/10.32479/ijeep.21858

ABSTRACT

This study investigates the impact of green economy factors on the sustainable development of Uzbekistan's agro-industrial complex using annual data from 1991 to 2024. The analysis focuses on key determinants such as electricity consumption, mineral fertilizer use, inflation, and renewable energy production, with the food production index serving as the dependent variable. Applying the autoregressive distributed lag (ARDL) model, both short- and long-run relationships were examined. The results demonstrate that renewable energy production and rational fertilizer use significantly enhance food production in the long term, while inflation exerts a negative influence, undermining production sustainability. Electricity consumption, however, showed no statistically significant long-run effect, highlighting that resource efficiency and diversification of energy sources are more crucial than total consumption. These findings underscore the strategic importance of green economy principles in strengthening food security, reducing environmental risks, and ensuring the resilience of the agro-industrial sector in Uzbekistan. The study provides empirical evidence to support policy measures aimed at expanding renewable energy use, promoting sustainable fertilizer management, and curbing inflationary risks to achieve long-term agricultural sustainability.

Keywords: Green Economy, Food Production, Renewable Energy, Agro-industrial Complex, ARDL Model, Uzbekistan
JEL Classifications: Q18, Q42, O13, Q56

1. INTRODUCTION

In recent decades, the issues of sustainable development and solving environmental problems have become one of the central topics in the global economy. In this process, the concept of a green economy is being formed as an important strategic direction not only for energy efficiency, but also for the sustainable development of agriculture and the agro-industrial complex. The agro-industrial sector is one of the key sectors of the economy, which plays a decisive role in ensuring food security, increasing export potential and developing employment. Therefore, its effective and environmentally sustainable development is one of the priority tasks of national economic policy.

The relationship between the use of energy resources and agricultural production has been widely discussed in scientific circles. On the one hand, energy consumption is an important factor in supporting production volumes, while on the other hand, reliance on traditional energy sources exacerbates environmental problems. Therefore, expanding the use of renewable energy resources is considered a prerequisite for ensuring the long-term efficiency of the agro-industrial complex.

In addition, macroeconomic factors, in particular the level of inflation, have a direct impact on the sustainability of production. Price fluctuations can stimulate producers in the short term, but in the long term they can undermine food security. In this context, controlling inflation and maintaining stable prices is essential to support agricultural production, in line with the principles of a green economy.

In the conditions of Uzbekistan, this issue is even more relevant. The country's agricultural sector, in addition to being the mainstay of the national economy, also has great potential in international markets. At the same time, climate change, inefficient use of resources and problems related to energy supply pose new challenges to the agro-industrial complex. In these conditions, an approach based on the concept of a green economy allows increasing production efficiency, strengthening energy independence and ensuring environmental sustainability.

On this basis, the purpose of this study is to determine the impact of green economy factors, in particular renewable energy production, mineral fertilizer use, and macroeconomic stability, on food production in the process of agro-industrial complex development. The ARDL model is used as an econometric approach to analyze short- and long-term relationships. The results of the study are of great importance not only scientifically, but also in the political decision-making process, serving to formulate practical recommendations for achieving sustainable development through the harmonization of energy economy and agricultural policy.

2. LITERATURE REVIEW

The concept of a green economy has been emerging as an important theoretical and practical direction in ensuring the development of the agro-industrial complex in recent decades. Globally, agricultural production requires the active use of many resources - energy, water and land resources. Therefore, extensive scientific research is being conducted to improve energy efficiency, use renewable energy sources and introduce environmentally sustainable production mechanisms in the agro-industrial system.

The integration of renewable energy sources into agriculture is increasingly recognized as a strategic approach to improving production efficiency and reducing environmental impacts. As conventional energy sources contribute significantly to greenhouse gas emissions, the transition to renewable energy sources such as solar, wind and biomass is essential for sustainable agricultural practices. This transition not only supports energy needs, but also stabilizes agricultural production and reduces the carbon footprint. The introduction of renewable energy technologies in agriculture has been shown to contribute to increased energy efficiency, reduced emissions and climate stability, thereby supporting a sustainable food future.

Energy efficiency and emission reduction: Renewable energy sources such as solar, wind and biomass can significantly improve energy efficiency in agriculture by reducing dependence on fossil fuels and reducing greenhouse gas emissions. This transition is critical for climate-resilient agriculture and a sustainable global food future (Kaundal, 2025).

The use of renewable energy in agriculture can provide significant cost savings and economic benefits. For example, solar and wind power projects have demonstrated energy efficiency and resilience to energy price fluctuations, increasing the economic viability of farms (Nazarov et al., 2024).

Renewable energy sources contribute to energy autonomy and reduced grid dependency, which is especially beneficial in remote or rural areas. This autonomy supports food price stability and improves rural economies by creating jobs (Gupta, 2025).

The integration of renewable energy into agriculture supports sustainable practices by reducing carbon footprints and promoting environmental protection. Technologies such as agrivoltaics and biomass conversion play a key role in achieving these sustainability goals (Sulewski and Wąs, 2024). Despite the advantages, the implementation of renewable energy technologies in agriculture faces challenges such as high initial costs, technological barriers, and the need for policy support. These challenges require innovation and supportive policy frameworks to encourage adoption (Hernandez-Escobedo et al., 2022).

The availability and management of renewable resources is crucial for successful integration. For example, the use of solar and wind energy requires specific geographical and climatic conditions that may not be available to everyone (Mehrotra, 2025). Effective policy frameworks and incentives are essential to promote the use of renewable energy in agriculture. These policies can stimulate innovation and support the expansion of renewable energy use in the sector (Fischer et al., 2006).

While the integration of renewable energy into agriculture has many benefits, it is important to consider the broader context of energy transition and food security. Agriculture's dependence on fossil fuels has historically led to productivity losses, but this dependence also brings risks such as price volatility and environmental degradation. Therefore, a balanced approach that includes renewable energy in addressing these challenges is essential for a sustainable future for agriculture. Collaborative efforts between policymakers, researchers and industry stakeholders are essential to support innovation and ensure the successful implementation of renewable energy technologies in agriculture (Ejedegba, 2024).

The impact of inflation on food production and economic stability is a multifaceted issue that affects agricultural productivity and sustainability. In the short term, inflation can stimulate production growth by raising nominal prices, which can increase farmers' incomes. However, in the long term, inflation can undermine production sustainability, increasing production costs and creating market inefficiencies that can limit the efficient use of resources. This dynamic highlights the importance of macroeconomic stability in supporting sustainable agricultural development, in line with the principles of a green economy.

Inflation can initially stimulate agricultural production by increasing nominal prices, which can increase farmers' incomes and encourage more production (Okezie et al., 2025). In some cases, moderate inflation can stimulate consumption and investment, providing a temporary boost to economic activity (Rofiqoh et al., 2025).

Over time, inflation leads to increased production costs, reduces farmers' incomes, and makes financial planning difficult for farmers (Yusdhika et al., 2025). High inflation rates can lead to price volatility, which disrupts market stability and planning, leading to inefficiency and misallocation of resources in agriculture (Ukoha et al., 2007). Inflationary pressures can also worsen the terms of trade between agriculture and other economic sectors, affecting productivity and equity (Lin et al., 2015).

Effective inflation control is essential for maintaining purchasing power and creating a stable economic environment conducive to long-term growth. Policies that stabilize macroeconomic variables, such as targeted economic policies and effective agricultural spending, are essential for ensuring agricultural productivity. Implementing policies that insulate the agricultural sector from the effects of inflation can minimize relative price volatility and improve resource allocation efficiency. Long-term strategies to stabilize agricultural prices and mitigate agflation include improving production planning and addressing labor shortages (Cano et al., 2014).

While inflation may bring short-term benefits to agricultural production, its long-term effects are usually detrimental, leading to increased costs and inefficiencies. Therefore, ensuring macroeconomic stability through effective policy measures is essential to support sustainable agricultural development and align with the principles of a green economy. This approach will not only help stabilize food production, but also contribute to broader economic stability and growth.

The rational use of mineral fertilizers is an important component of agro-industrial policy within the framework of a green economy. While mineral fertilizers are necessary to increase agricultural productivity, their excessive use can cause significant environmental problems, such as soil degradation and pollution. Therefore, a balanced approach is needed that maximizes productivity while minimizing environmental impacts. This includes the cost-effectiveness of fertilizers, their environmental impact, and the development of sustainable agricultural practices.

The economic efficiency of mineral fertilizers is determined by their economic efficiency and safety, which are assessed by various indicators, including field experiments and cost analysis (Makarenko and Repetska, 2023). Inefficient use of fertilizers can lead to nutrient accumulation, which can cause environmental problems such as soil and water pollution (Sarteel et al., 2016). For example, excessive use of nitrogen can cause environmental pollution and health hazards (Rudinskaya and Náglová, 2017). The economic cost of nutrient pollution in the European Union is significant, estimated at €7 billion to €10 billion/year (Nakachew et al., 2024).

Sustainable practices include precise nutrient management that optimizes fertilizer efficiency and supports agricultural sustainability. The use of encapsulated fertilizers significantly reduces environmental pollution compared to traditional granular fertilizers, increasing both productivity and environmental safety (Synelnikov et al., 2019). Balanced fertilization and minimal use of chemicals help reduce greenhouse gas emissions and environmental degradation (Bashir et al., 2022).

Studies conducted in the northern steppes of Ukraine have shown that the rational use of mineral fertilizers can increase yields without significantly increasing the content of heavy metals and nitrates in crops (Tsyliuryk et al., 2020). In the European Union, some member states have demonstrated relatively high environmental performance in plant production, indicating the potential for improving management techniques and policies.

Developing nonlinear regression models can help understand the relationship between soil nutrient levels and yield, helping to ensure efficient use of fertilizers (Shikhova et al., 2023). Innovative technologies such as remote sensing and GIS improve nutrient management and contribute to sustainable agriculture.

While the rational use of mineral fertilizers is essential for increasing food production, it is equally important to consider the environmental consequences of their use. The integration of sustainable practices, technological innovations and effective management strategies can help mitigate the negative environmental impacts of fertilizers. Such a balanced approach is necessary to achieve a green economy in agriculture, ensure food security and maintain ecological integrity.

In order to increase production in the agro-industrial complex, it is indeed more important to improve the quality of resource utilization mechanisms than to increase energy consumption. This perspective emphasizes the importance of diversifying and integrating renewable energy sources in energy policy. The focus is on improving energy efficiency and introducing innovative practices to ensure sustainable production in agriculture. This approach not only addresses the limitations of traditional energy sources, but is also consistent with global sustainability goals.

Energy efficiency involves using less energy to achieve the same level of agricultural output, given the limited growth in energy production and the finite nature of traditional energy sources (Vijayakumar et al., 2023). Strategies such as conservation agriculture, organic farming, and improved soil and water management can significantly increase energy efficiency without compromising productivity. Advanced mechanization and food processing technologies are also important in improving energy efficiency in agriculture (Halmuratov et al., 2025).

Renewable energy sources such as solar, wind, biomass and geothermal offer significant potential to reduce the carbon footprint and increase the economic viability of farms (Nazarov et al., 2024). Renewable energy integration in agriculture not only supports energy efficiency, but also provides resilience to energy price fluctuations. Case studies have shown successful implementation of renewable energy projects on farms, leading to cost savings and increased energy efficiency (Yulduz et al., 2025).

Diversifying energy sources is crucial for energy security and reducing dependence on external energy supplies (Ozturk, 2013). The use of renewable energy sources in the agro-industrial sector can optimize costs and increase competitiveness, as seen in various regions, including the European Union and Latin America (Dudin et al., 2019). A grid energy model that combines traditional and renewable energy sources can ensure the sustainable development of agro-industrial enterprises.

Public policies and incentives play an important role in promoting the use of renewable energy in agriculture. Innovative approaches to energy management, such as energy audits and energy management systems, are needed to identify the optimal mix of energy resources. Developing optimal models for the use of renewable energy sources at the local level is important for sustainable rural development (Gorb et al., 2020).

While it is clear that there is a strong focus on improving resource efficiency and integrating renewable energy, it is also important to consider the challenges associated with these approaches. The transition to renewable energy requires significant investment and policy support, which is not available in all regions. In addition, the initial costs of implementing advanced technologies and renewable energy systems can be prohibitive for smallholder farmers. Therefore, a balanced approach that includes both energy efficiency improvements and the gradual integration of renewable energy sources, supported by appropriate policies and incentives, is essential for the sustainable development of the agro-industrial complex (Xolmurotov and Xolmuratov, 2025).

In summary, the existing scientific literature shows the importance of a green economy for the agro-industrial complex in three main directions. First, it ensures the sustainability of production through renewable energy resources. Second, it is a guarantee of macroeconomic stability, in particular, curbing inflation, food security and production efficiency. Third, the rational use of resources, especially fertilizer consumption, increases productivity and ensures environmental sustainability. At the same time, the principles of a green economy are being considered as a strategic direction for the agro-industrial complex, in line with global energy policy, climate change and sustainable development goals.

3. RESEARCH METHODS

In this study, the factors influencing the development of the agro-industrial complex were analyzed using economic and econometric methods based on a 34-year time series from 1991 to 2024. The food production index (food_prod_idx) was selected as the main dependent variable. The independent variables included electricity consumption (elec_cons_kwh), fertilizer consumption (fert_cons_kg), inflation (infl_gdp_defl), and renewable energy production (ren_elec_out). All variables were converted to natural logarithms, which allowed the estimated coefficients to be interpreted as elasticity.

The Augmented Dickey–Fuller (ADF) test was used to determine the stability of the statistical properties of the time series (Fozil et al., 2025). According to the test results, electricity consumption was found to be stationary in the rank value (I(0)), while all other variables were found to be stationary in the first difference (I(1)). Therefore, the study contains a mixture of I(0) and I(1) processes, which provides a theoretical basis for applying the ARDL approach.

The Autoregressive Distributed Lag (ARDL) model is a convenient approach that allows us to identify short- and long-run effects. In general, the ARDL($p,q_1,q_2,\ldots,q_k$) model is expressed as follows:

$$\Delta y_t = \alpha_0 + \sum_{i=1}^{p}\phi_i \Delta y_{t-i} + \sum_{j=1}^{k}\sum_{i=0}^{q_j}\beta_{ji}\Delta x_{jt-i} + \lambda\left(y_{t-1} - \sum_{j=1}^{k}\theta_j x_{jt-1}\right) + \varepsilon_t$$

Where y_t is the dependent variable (ln food_prod_idx), x_{jt} is the vector of independent variables, ϕ_t and β_{jt} are short-run dynamic coefficients, θ_j is the long-run coefficient, λ is the error correction coefficient.

The optimal lag length was selected using Akaike (AIC), Hannan–Quinn (HQIC), final prediction error (FPE), and Schwarz Bayesian (SBIC) criteria. As a result, the ARDL(2,0,0,2,0) model was accepted as the most suitable option (Halmuratov et al., 2025).

To determine the presence of a long-run relationship, the Bounds test proposed by Pesaran et al. (2001) was used. This test determines whether or not there is a cointegrating relationship between variables by comparing the values of the F-statistic and t-statistic with the critical values of I(0) and I(1). The results confirmed the existence of a stable long-run relationship between food production and the main determinants.

In order to ensure the adequacy of the model and the reliability of the evaluation results, a number of diagnostic tests were conducted: Breusch–Godfrey LM test: showed that there was no autocorrelation in the residuals, Breusch–Pagan/Cook–Weisberg test: no heteroscedasticity was detected, Jarque–Bera test: confirmed that the residuals conformed to a normal distribution, Ramsey RESET test and Linktest: showed that the model specification was correctly selected.

Thus, using the ARDL model, the short- and long-term relationships of food production with energy consumption, fertilizer use, inflation, and renewable energy production were identified, and the model provided stable and mathematically sound results for economic interpretation.

4. RESULTS AND DISCUSSION

The descriptive statistics presented at this stage are essential for the study because they reveal the general characteristics of the data set and provide a solid foundation for further econometric modeling (Table 1). The mean, standard deviation, minimum and maximum values of the studied variables help to understand how they fluctuate over time and the degree of stability.

The food production index is relatively stable, with no sharp changes. Electricity consumption also has very small fluctuations, confirming the stability of energy supply. Fertilizer consumption shows moderate volatility, indicating a certain flexibility in the use of resources in agriculture. The inflation index has significant

Table 1: Descriptive statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
ln food prod idx	34	4.038	0.512	3.045	4.816
ln elec cons kwh	34	7.48	0.094	7.384	7.776
ln fert cons kg	34	5.364	0.229	4.955	5.717
ln infl gdp defl	34	3.536	1.34	1.381	7.122
ln ren elec out	34	2.811	0.234	2.41	3.135

Table 2: Unit root test results (random walk without drift, d=0)

Variable name	ADF test	
	At level	First-difference
ln_food_prod_idx	−0.338 (0.9199)	−12.357 (0.000)
ln_elec_cons_kwh	−5.801 (0.000)	
ln_fert_cons_kg	−1.610 (0.4779)	−6.463 (0.000)
ln_infl_gdp_defl	−2.156 (0.2227)	−5.242 (0.000)
ln_ren_elec_out	−2.016 (0.2796)	−9.566 (0.000)

fluctuations, indicating that economic instability can have a strong impact on food production. Renewable energy production has relatively consistent growth, indicating the sustainable development of resources.

This analysis shows that while the main determinants of food production have different volatility, electricity and renewable energy production stand out as stability factors. Inflation shocks are also a source of risk in the production process. Thus, the results of descriptive statistics provide the necessary initial insights for the stationarity test, ARDL model, and cointegration analysis used in the subsequent steps.

The introduction of the ADF test is of particular importance in research methodology, because in time series analysis, the stationarity of variables is one of the main conditions for the reliability and interpretation of model results.

The results show that the food production index, fertilizer consumption, inflation, and renewable energy production are not stationary in the level values, but are stationary in the first difference (Table 2). This indicates that they belong to an I(1) process. In other words, these variables are not stable at their initial levels over time, but reach equilibrium in differential form.

Electricity consumption, on the other hand, was found to be stationary at the level of the process I(0). This means that the variables used in the study were confirmed to be stationary at different levels. This is methodologically convenient for the ARDL approach, since the ARDL model allows for the simultaneous use of variables in the form of I(0) and I(1). Thus, the stationarity analysis provided a solid foundation for the cointegration tests and the identification of long- and short-run effects that were carried out in the subsequent stages.

The lag selection step is one of the most important processes in building an ARDL model, determining how reliably the model reflects short- and long-term effects.

As can be seen from the results presented in Table 3, different lag options were compared using different criteria - Akaike Information Criterion (AIC), Hannan-Quinn (HQIC), Final Prediction Error (FPE) and Schwarz Bayesian Information Criterion (SBIC). At Lag 0, the indicators were high, and the model did not fit well enough in terms of quality. Although the criteria improved significantly at Lag 1 and Lag 2, this level was not selected as the optimal result. At Lag 3, the model quality improved further, and the AIC and HQIC values decreased sharply. The most optimal result was observed at Lag 4, where the smallest or most negative values were recorded for all criteria.

This means that the Lag 4 model is chosen as the most suitable option for the ARDL approach. Although SBIC indicated that Lag 1 was also acceptable in some cases, most of the general criteria supported Lag 4. Therefore, the choice of lag level 4 allows the model to more fully express dynamic relationships, more accurately reflect short-term fluctuations, and more reliably identify long-term dependencies. As a result, the selected lag structure serves as an important basis for increasing the reliability of subsequent ARDL analyses.

The results of the ARDL(2,0,0,2,0) model show that the food production index is sensitive to different factors in the short and long term (Table 4). The values of R^2 = 0.8521 and Adj R^2 = 0.8007 of the model indicate that it has high explanatory power, explaining about 85% of the variance of the variables. The low value of Root MSE also indicates that the model error rate is small and confirms the reliability of the results.

The analysis of long-term effects revealed that fertilizer consumption and renewable energy production had a significant positive effect, while inflation had a negative and strong effect. These results indicate that the efficient use of mineral fertilizers in agriculture and the expansion of renewable energy production ensure sustainable growth in food production. Conversely, high inflation rates can reduce production. Electricity consumption, on the other hand, did not reach statistical significance in the long-term effect, i.e., there was no strong relationship between total electricity consumption and food production.

The short-term results show a slightly more complex picture. Inflation has acted as a short-term stimulus to production, encouraging producers to produce more. However, in the long run, this trend is not sustainable, and the negative effects of inflation eventually prevail. In addition, the previous period differences in the food production index are negative and significant, confirming the existence of short-term adjustment processes.

Overall, the ARDL model identifies fertilizer consumption and renewable energy as the main determinants of food production, while inflation is a risk factor for production sustainability. The insignificant output of electricity consumption means that this factor can only affect indirectly or through other mechanisms. The high explanatory power of the model indicates that the results serve as a reliable basis for economic interpretation.

The bounds test is an important step in the ARDL model, as it allows us to determine whether there is a long-term relationship between variables. Because even if there are short-term fluctuations in time

Table 3: Lag selection criteria

Lag	LR	df	P-value	FPE	AIC	HQIC	SBIC
0	63.7463	—	—	1.4e-08	−3.91642	−3.84171	−3.68289
1	197.113	266.73	25	0.000	1.0e-11	−11.1408	−10.6926
2	225.966	57.707	25	0.000	9.2e-12	−11.3977	−10.5759
3	271.009	90.087	25	0.000	3.8e-12	−12.734	−11.5386
4	313.528	**85.037***	25	0.000	**3.4e-12***	**−13.9019***	**−12.333***

Note: Bold values with asterisks () indicate the optimal lag length selected by each criterion (FPE, AIC, HQIC, SBIC).*

Table 4: ARDL (2,0,0,2,0) regression results

Sample:	1992 thru	2023	Number of obs=32			
			R-squared=0.8521			
			Adj R-squared=0.8007			
Log likelihood=64.041446			Root MSE=0.0386			
D.						
ln_food_prod_idx	**Coefficient**	**Std. err.**	**t**	**P>t**	**[95% conf. interval]**	
ADJ						
ln_food_prod_idx						
L1.	−0.193	0.045	−4.300	0.000	−0.285	−0.100
LR						
ln_elec_cons_kwh	−0.384	1.523	−0.250	0.803	−3.534	2.766
ln_fert_cons_kg	0.674	0.215	3.140	0.005	0.230	1.118
ln_infl_gdp_defl	−0.243	0.063	−3.840	0.001	−0.374	−0.112
ln_ren_elec_out	0.748	0.285	2.630	0.015	0.159	1.337
SR						
ln_food_prod_idx						
LD.	−0.323	0.070	−4.590	0.000	−0.469	−0.178
ln_infl_gdp_defl						
D1.	0.032	0.014	2.340	0.028	0.004	0.060
LD.	0.059	0.012	4.970	0.000	0.034	0.083
_cons	0.463	2.192	0.210	0.835	−4.071	4.997

series analysis, their long-term trends are crucial for economic interpretation. If the existence of cointegration is confirmed, it will be possible to interpret the long-term coefficients obtained from the ARDL model with confidence.

Pesaran, Shin, and Smith (2001) bounds test
H0: no level relationship F=4.817
Case 3 t=−4.300
Finite sample (4 variables, 32 observations, 3 short-run coefficients)
Kripfganz and Schneider (2020) critical values and approximate
P values

10%		5%		1%		P-value	
I (0)	I (1)	I (0)	I (1)	I (0)	I (1)	I (0)	I (1)
2.730	4.032	3.353	4.852	4.892	6.862	0.011	0.051
−2.536	−3.651	−2.909	−4.092	−3.684	−5.006	0.003	0.035

The test results show that the calculated F-statistic is 4.817, which is above the upper critical value at the 10% level but slightly below the upper critical value at the 5% level. This indicates that there is a long-run relationship at the 10% level. The t-statistic is also −4.300, which is below the 5% critical value, which also confirms the presence of cointegration.

The general conclusion is that food production and its determinants – fertilizer consumption, renewable energy production and inflation – have a stable long-term relationship over time. This means that after short-term fluctuations, the system returns to equilibrium and that economic interpretations are valid.

Diagnostic tests are essential for reliable interpretation of results from ARDL models, as they check the nature of the residuals and ensure the stability and accuracy of the regression estimates. If there is autocorrelation, heteroscedasticity, or deviation from normal distribution, the statistical significance of the coefficients may be incorrectly estimated. Therefore, the Breusch–Godfrey, Breusch–Pagan/Cook–Weisberg, and Jarque–Bera tests are important to strengthen the quality of the model and the reliability of the economic interpretation.

BreuschвЂ“Godfrey LM test for autocorrelation chi2	df	Prob>Chi2
0.792	1	0.374
H0: no serial correlation		

The results show that the Breusch–Godfrey LM test yielded χ^2 (1) = 0.792 and P = 0.374. Since the P > 0.05, it is confirmed that there is no serial correlation in the residuals. This indicates that the dynamic structure of the model is appropriate and there is no systematic dependence in the errors.

The Breusch–Pagan/Cook–Weisberg test yielded $\chi^2(1) = 0.37$ and P = 0.5432. Since this is also >0.05, the residual variance is stable, i.e., heteroscedasticity was not detected. Therefore, the estimated standard errors are reliable, and the conclusions drawn from the coefficients are stable.

The Jarque–Bera normality test showed a result of JB = 0.0061 and P ≈ 0.997. This confirms that the residuals follow a normal distribution, as a result, the conclusions drawn from the t-test and F-tests are reasonable, and the normal approximation is well ensured even in small samples.

In general, diagnostic tests confirmed that the ARDL model does not suffer from autocorrelation, heteroscedasticity, or normality problems. Therefore, the short- and long-run coefficients obtained from the model serve as a reliable basis for economic interpretation.

The Ramsey RESET test is necessary to check whether the ARDL model is correctly specified, because it captures the presence of nonlinear terms or important factors that have been neglected in the regression through the residual structure. When working with time series, if there is a functional form error, the coefficients and their significance are incorrectly estimated, so the RESET test is performed to ensure the reliability of the long- and short-term interpretations.

Ramsey RESET test for omitted variables

Omitted: Powers of fitted values of ln_food_prod_idx

H0: Model has no omitted variables

$F(3, 26) = 0.64$

Prob > F = 0.5959

The study results showed an F-value of 0.64 and a $P = 0.5959$, which does not reject the main hypothesis and indicates that there is no evidence of significant missing factors or nonlinearity in the model. At the same time, previously conducted diagnostic tests showed the absence of serial correlation, dispersion stability and compliance of residuals with a normal distribution, which means that the model successfully passed the general diagnostic criteria and the selected lag structure and the included determinants adequately represent the economic process. As a result, the long- and short-term estimates obtained from the ARDL model are stable and reliable for interpretation.

Linktest is used to check whether a model is well-specified, as it adds the predicted value (_hat) and its square (_hatsq) to the regression, allowing it to detect whether the result contains large omitted variables or an incorrect functional form. If the model is well-specified, _hat should be significant and _hatsq should be insignificant.

According to the results of this test, the coefficient for _hat is 0.187 ($P = 0.897$) and the coefficient for _hatsq is 0.102 ($P = 0.573$), both values are statistically insignificant. This means that there is no evidence that the model has omitted important factors or has an incorrect functional form. The overall model quality is high, with $R^2 = 0.9128$ and Adjusted $R^2 = 0.9071$ indicating that the model has very high explanatory power.

4.1. Discussion

The results of this study allow us to better understand the role and importance of the green economy in the development of the agro-industrial complex. The empirical results obtained showed that the sustainability of food production is largely related to the rational use of resources and energy efficiency. In particular, the efficient use of renewable energy sources and mineral fertilizers has emerged as the main determinants of stimulating production in the long term. This confirms the strategic importance of the principles of the green economy in the agro-industrial complex.

The negative impact of inflation highlights the importance of macroeconomic stability in the production process. While sharp price fluctuations may provide short-term incentives for producers, they increase economic risks in the long run and negatively affect food security. In this context, policies to curb inflation not only ensure macroeconomic stability but also serve as an important component of the green economic transformation.

The positive impact of renewable energy production indicates the need to expand renewable sources as a priority in energy policy. In the context of increasing energy demand in the agro-industrial complex, being limited to traditional energy sources exacerbates environmental risks. Therefore, it is possible to increase the resource efficiency of agro-industrial production and reduce its carbon footprint through the wider use of sources such as solar, wind and biomass. This not only ensures economic efficiency, but also serves the goals of environmentally sustainable development, in line with international energy policies.

Another important finding of the study is that total electricity consumption did not have a significant impact on the volume of food production. This suggests that energy efficiency and diversification of sources are more important than the volume of energy consumption. That is, increasing production does not necessarily mean consuming more energy, but rather managing existing resources more efficiently and increasing the share of renewable energy.

In general, the results obtained show that the application of the green economy concept in the agro-industrial complex yields positive economic, social, and environmental results. This is an important strategic direction in ensuring agricultural and food security in the conditions of Uzbekistan, and, in combination with international experience, accelerates the achievement of sustainable development goals.

Therefore, the main recommendations for politicians and decision-makers are: increasing productivity through rational use of resources in agriculture, strengthening energy independence by expanding renewable energy sources, ensuring production stability by curbing inflation risks, and developing institutional and financial mechanisms for a green economy. These measures will not only sustainably develop the agro-industrial complex, but also provide consistent results in important areas of energy economics and policy at the international level.

5. CONCLUSION

The results of this study showed the strategic importance of the principles of a green economy in the development of the agro-industrial complex. Empirical analysis confirmed that renewable energy production and rational use of mineral fertilizers significantly increase the volume of food production in the long term. This indicates that it is possible to ensure sustainable growth in production through the efficient use of resources. On the contrary, it was found that the inflation process has a negative impact in the long term and undermines the stability of production. The total volume of electricity consumption, as expected, did not have a significant impact, which indicates the importance of efficiency and source diversification rather than energy volume.

Using the ARDL model and cointegration tests, short- and long-run dynamics were studied, and a stable relationship between food production and its main determinants was demonstrated. Although inflation acts as a stimulus for producers in the short run, it was found that this effect is not sustainable in the long run. This emphasizes the importance of macroeconomic policy in ensuring agricultural and food security.

The main lesson from the study is that the development of the agro-industrial complex based on the principles of a green economy will ensure not only economic efficiency, but also environmental sustainability in the conditions of Uzbekistan. In this regard, several practical recommendations can be put forward for policymakers. First, it is necessary to make wider use of renewable energy sources and integrate them into the agro-industrial system. Second, by developing systems for the rational use of mineral fertilizers, it is possible to increase productivity while ensuring environmental safety. Third, curbing the risk of inflation is an important condition for the sustainability of food production.

Overall, this study has shown that the concept of a green economy is a crucial factor in the sustainable development of the agro-industrial complex of Uzbekistan. The results contribute to the international scientific literature and policy discussions, and provide an important theoretical and practical basis for future research in energy economics, agricultural policy, and sustainable development.

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