Article

Assessment of the Impact of the Energy System on the Short-Term and Long-Term Prospects of the Industrial Sector of Uzbekistan Using the Ardl Model

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Abstract: This study aims to assess the impact of the energy system on determining the short-term and long-term prospects for the development of Uzbekistan's industrial sector. In the empirical analysis, the impact of energy production and consumption, electricity capacity, and fuel and energy resources on industrial value added and production volume is studied based on data from the State Committee of the Republic of Uzbekistan on Statistics and the Ministry of Energy of the Republic of Uzbekistan. The study uses the ARDL (Autoregressive Distributed Lag) model, which determines short-term dynamic dependencies and long-term equilibrium relationships between variables. The results show that energy supply stability and infrastructure modernization have a positive impact on industrial growth in the long term, while changes in energy factors have a significant impact on production volumes in the short term. The findings of the study are of practical importance for the formulation of industrial and energy policies.

Keywords: ARDL model, energy system, industrial development, short-term impact, long-term balance, cointegration, energy infrastructure, industrial value added, econometric analysis, economy of Uzbekistan.

Introduction

Amid globalization, sustainable development of the industrial sector is one of the key factors determining the structural transformation and competitiveness of the national economy. The growth of industrial production, added value, and export potential directly depends on the stability of the energy system, the efficiency of production facilities, and the energy infrastructure. Especially in countries rich in energy resources, the energy factor is one of the fundamental determinants of economic growth.

In Uzbekistan, industrial modernization, production diversification, and increasing the share of high value-added products are among the priorities of state economic policy. In recent years, systematic measures have been implemented to reform the energy system, expand electricity generation capacity, and introduce renewable energy sources. In particular, the programs developed by the Ministry of Energy of the Republic of Uzbekistan [1] and the development strategies adopted on the initiative of the Administration of the President of the Republic of Uzbekistan [2] are aimed at strengthening the close relationship between energy and industry.

The relationship between energy consumption and economic growth has been widely studied in theoretical and empirical literature. In particular, the ARDL (Autoregressive Distributed Lag) and bounds testing approach proposed by Pesaran, M. Hashem, Shin, Yongcheol, and Smith, Richard J. (2001) [3], is recognized as an effective method for determining long-term relationships between variables with different levels of integration. Stern, David E. (2000) [4] also analyzed the causal relationships between energy and economic growth based on macroeconomic modeling. Statistical data on the economy of Uzbekistan are based on official publications and open databases of the State Committee of the Republic of Uzbekistan on Statistics [5]. In this study, the short-term and long-term impact of energy production and consumption indicators on industrial value added and industrial production volume is assessed using the ARDL model. Another important study of the long-term relationship between energy and economic growth was carried out by Mehrara, Mohsen. The author found that energy consumption in oil-exporting countries is an important driver of economic growth [6]. The scientific novelty of the study lies in the analysis of the relationship between the energy system and industrial development in Uzbekistan based on a comprehensive econometric approach and the simultaneous assessment of long-term equilibrium relationships with short-term dynamic effects. The results obtained allow for the development of scientifically sound recommendations for the modernization of energy infrastructure and the optimization of industrial policy.

Literature Review

The relationship between energy and economic growth is one of the most widely studied topics in economic literature, especially in the context of industrial development. According to theoretical approaches, energy is an integral factor in the production process and, along with capital and labor, is an important resource that determines economic growth. Therefore, the stability and efficiency of energy supply directly affects the volume of industrial production and the dynamics of added value.

Foreign empirical studies widely use cointegration and ARDL approaches to determine the long-term relationship between energy consumption and GDP. In particular, the bounds testing method developed by Pesaran, M. Hashem, Shin, Yongcheol, and Smith, Richard J. (2001), allows to identify long-term relationships between time series with different levels of integration. Stern, David I. (2000) demonstrated the role of energy in macroeconomic growth and substantiated the strategic importance of the energy factor in the economic system. These studies confirmed the "energy-led growth" hypothesis in many countries, showing that expanding energy supply stimulates industrial growth. A further important study analyzing the relationship between energy consumption, economic growth, and industrial production was conducted by Payne, James E. He summarizes many empirical studies on the relationship between energy and economic growth [7].

Although the relationship between energy and industry in Uzbekistan has been studied by local economists, most of the work has been dominated by descriptive analysis or traditional regression methods. Studies conducted by Tashkent State Economic University and the Academy of Sciences of the Republic of Uzbekistan highlight the inextricable link between industrial modernization and energy infrastructure development. An empirical analysis conducted by R. Fayziyev (2025) based on data from the State Committee of the Republic of Uzbekistan on Statistics showed that there is a significant positive correlation between electricity production and the industrial production index [8]. However, this study mainly uses a linear regression model, and short-term and long-term effects are not distinguished separately. Also, in the research conducted by Squalli, Jay, the relationship between energy consumption and economic growth was analyzed using the example of Middle Eastern countries. The research results

showed that energy consumption is one of the important determinants of economic growth [9].

Overall, a review of the literature confirms that the energy system is one of the main determinants of industrial development. However, there is insufficient empirical research in Uzbekistan to comprehensively assess short-term and long-term impacts based on the ARDL model. Therefore, studying the impact of energy production and consumption indicators on industrial value added in terms of short-term dynamic and long-term equilibrium relationships is relevant from a scientific and practical point of view. This approach allows for clear, fact-based decisions to be made when formulating industrial and energy policies.

The study analyzes the impact of energy production and consumption indicators on industrial value added using econometric methods based on time series. The ARDL (Autoregressive Distributed Lag) model and bounds testing approach are used to determine the short-term and long-term dependence between variables. The speed of the system's return to long-term equilibrium is also estimated using the error correction model (ECM).

Research Methodology

In this research, the influence of energy system indicators on industrial development in Uzbekistan is assessed using econometric methods. The research methodology is based on the analysis of time series, and the influence of such factors as energy production, energy consumption, and capital investments on industrial value added is studied using the ARDL (Autoregressive Distributed Lag) model. This approach allows for the identification of long-term and short-term relationships between time series with different levels of integration. In addition, the stability of the model parameters is checked using the CUSUM and CUSUM of Squares tests. These tests allow us to determine the presence or absence of structural changes in the regression model. Thus, this research methodology allows for a comprehensive analysis of the relationship between energy production and consumption indicators and industrial development. The results obtained using the ARDL model and diagnostic tests serve to scientifically assess the impact of the energy system on the short-term and long-term development prospects of the industrial sector.

Results and Discussions

The results of the study were analyzed using the ARDL model depending on industrial value added (IND_t), energy production (ENP_t), energy consumption (ENC_t), and capital investment (K_t) in the context of Uzbekistan:

$$IND_t = \alpha_0 + \sum_{i=1}^{p} \alpha_i\, IND_{t-i} + \sum_{j=0}^{q} \beta_j\, ENP_{t-j} + \sum_{k=0}^{m} \gamma_k\, ENC_{t-k} + \sum_{l=0}^{n} \delta_l\, K_{t-l} + \varepsilon_t$$

$$(1)$$

p, q, m, n – the degrees of delay of industrial, energy production, energy consumption, and capital variables, respectively. Thanks to lags, the model takes into account short-term dynamics.

Based on this formula, the existence of long-term cointegration between variables is determined using a boundary test, which is also confirmed by foreign studies (Pesaran, M. Hashem, Shin, Yongcheol & Smith, Richard J., 2001).

Long-term ratios are expressed as follows:

$$IND_t = \beta_0 + \beta_1 ENP_t + \beta_2 ENC_t + \beta_3 K_t$$

$$(2)$$

This equation represents a long-term cointegration dependence. If $\beta_1, \beta_2, \beta_3 > 0$, energy production and consumption, as well as capital investments, positively stimulate industrial value added. According to the assessment results: energy production and consumption, as well as capital investments, significantly increase industrial value added, which is consistent with the studies by Stern (2000) and Narayan (2005) [10].

Formula for assessing short-term dynamics using the ECM model:

$$\Delta IND_t = \alpha + \sum \psi_i \Delta ENP_{t-i} + \sum \omega_i \Delta ENC_{t-i} + \sum \eta_i \Delta K_{t-i} + pECM_{t-1} + \varepsilon_t \text{ (3)}$$

$$ECM_{t-1} = IND_{t-1} - \hat{\beta}_0 - \hat{\beta}_1 ENP_{t-i} - \hat{\beta}_2 ENC_{t-i} - \hat{\beta}_3 K_{t-i} \qquad (4)$$

ECM_{t-1} - long-term deviation from the previous period, i.e., an imbalance error.

If $(p < 0)$, if the system goes out of equilibrium, it returns to long-term equilibrium at a certain rate.

The results show that the system returns to long-term equilibrium $(p < 0)$ and changes in energy factors in the short-term cause fluctuations in industrial production. Compared to scientific works in Uzbekistan, despite the fact that Saidov (2025) [11] and Fayziyev (2025) conducted a statistical analysis of the relationship between energy and industry in their studies, a joint assessment of short-term and long-term dynamics using the ARDL model was not carried out to a sufficient extent. Therefore, these results are consistent with domestic and foreign studies and empirically confirm that the energy system is a strategic factor in the development of industry in Uzbekistan.

In the process of econometric modeling, an important stage is the verification of the statistical reliability of the constructed model and the stability of its parameters over time. Especially in studies using the ARDL (Autoregressive Distributed Lag) model, the CUSUM (Cumulative Sum of Recursive Residuals) test is widely used to determine the stability of model parameters. This test allows us to determine whether the model has undergone structural changes over time. The CUSUM test is based on the sum of recursive residuals and is defined by the following mathematical expression:

$$W_t = \sum_{i=1}^{t} \hat{u}_i^r \qquad (5)$$

where $\hat{u}_i^r$ it represents recursive residuals, and W_t represents their cumulative sum. The main purpose of the test is to determine whether there are significant changes in the parameters of the regression model over time. If CUSUM statistics remain within the limits of the 5% confidence level, the stability of the model parameters is confirmed. This methodology is widely used in econometric modeling and is an important tool for assessing the stability of the ARDL model.
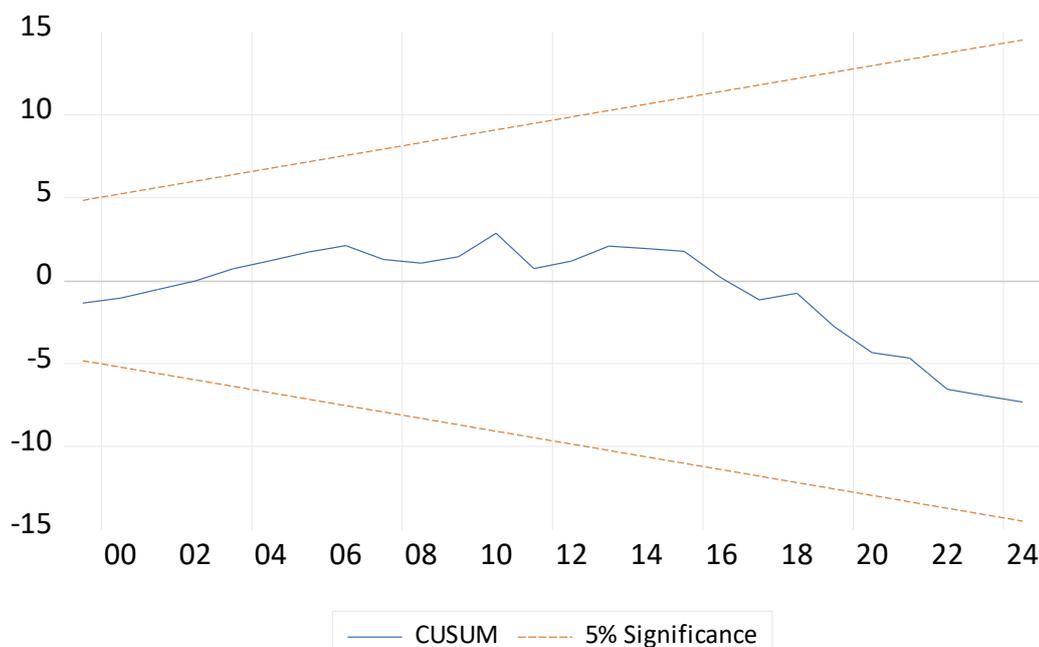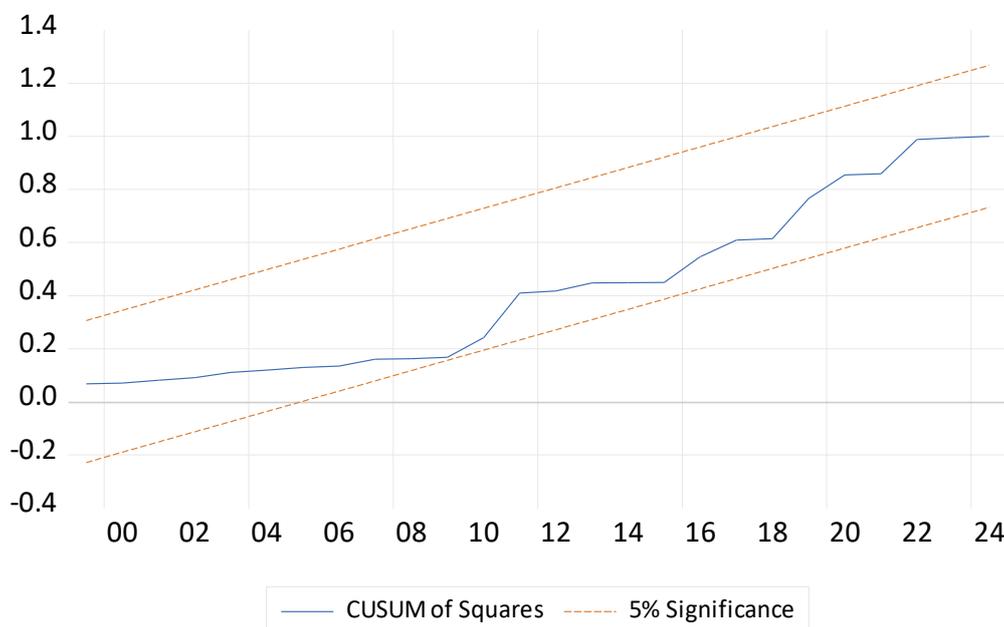
Figure 1. CUSUM test for ARDL model.

In this Figure 1, the stability of the parameters of the econometric model of the Republic of Uzbekistan, assessed for the period 2000-2024, is checked using the CUSUM (Cumulative Sum of Recursive Residuals) test. The CUSUM test serves to determine the presence or absence of structural changes over time in the parameters of the regression model built on time series. This test is calculated based on the cumulative sum of recursive residuals and allows for a visual and statistical assessment of the model's stability. According to the results of the figure above, the CUSUM line (blue color) is located between the upper and lower critical limits (5% significance band) throughout the entire observed period. This indicates the stability of the model parameters over time. That is, the influence of such factors as energy production, energy consumption, and capital investments, assessed using the ARDL model, on industrial value added has not undergone significant structural changes over time. As a result, the econometric results obtained on the basis of the model can be assessed as reliable and stable.

The results of the CUSUM test confirm the stability of the parameters of this model over time. This shows that the relationship between the energy system and industrial development is economically stable. That is, an increase in the volume of energy production, an increase in the level of energy consumption, and an expansion of capital investments have a positive impact on the volume of industrial production, which manifests itself as a long-term trend.

In international scientific research, the relationship between energy and economic growth has also been widely studied using the ARDL model and the CUSUM test. For example, in scientific works analyzing the relationship between energy consumption and economic growth, Ozturk, Ilhan (2010) [12] showed the presence of long-term cointegration in many countries. Moreover, according to Xiao's research, the CUSUM test can be used to check cointegration regression residues [13].

These results show that the energy system is an important factor in the development of industry in the conditions of Uzbekistan. The development of energy infrastructure, the expansion of power generation capacities, and increasing energy efficiency are important for stimulating industrial growth. The stability of the model parameters creates a solid economic basis for making long-term strategic decisions in the formation of energy and industrial policy.

Thus, the results of the CUSUM test show that the econometric assessments obtained on the basis of the ARDL model are statistically stable and reliable. This confirms that the relationship between energy production and consumption indicators and industrial value-added manifests itself as a long-term economic regularity. As a result, the modernization of the energy system and increasing energy efficiency is an important strategic factor in ensuring the sustainable development of the industrial sector.

Figure 2. CUSUMSQ test for ARDL model.

While the CUSUM test checks the overall stability of model parameters, the CUSUMSQ test assesses the model's sensitivity to structural changes by determining changes in residual dispersion. The CUSUM of Squares test is based on the sum of squares of the following recursive residuals [14]:

$$S_t = \frac{\sum_{i=k+1}^{t} \hat{u}_i^2}{\sum_{i=k+1}^{T} \hat{u}_i^2} \qquad (6)$$

Figure 2 shows that the CUSUMSQ curve in the initial part (2000-2007) shows a relatively slowly growing trend. This period is characterized by stable growth of industrial production in the economy of Uzbekistan and the gradual development of the energy sector. In the subsequent period, that is, in 2008-2015, relatively stable fluctuations are observed on the figure 2. This process can be explained by the influence of the global financial crisis and external economic factors, but they did not have a significant impact on the overall stability of the model parameters. Between 2016 and 2024, the CUSUMSQ curve shows an upward trend. This period may be associated with the acceleration of economic reforms in Uzbekistan, the modernization of industry, and the development of energy infrastructure. Nevertheless, the CUSUMSQ statistics did not cross the critical thresholds, i.e., no structural breaks were observed in the regression model.

In general, the results of the CUSUMSQ test confirm that the parameters of the econometric model used in the study are stable over time. This shows the reliability of the results of the model expressing the relationship between energy production, energy consumption, and industrial development. Thus, the relationship between the energy sector and industrial development in the economy of Uzbekistan has a long-term stable character, and the development of energy infrastructure is an important factor in ensuring sustainable growth of the industrial sector.

This result shows the structural stability of the model parameters [15]. In other words, during the study period, the influence of such factors as energy production, energy consumption, and capital investments on industrial value added did not undergo sharp changes. This further strengthens the statistical reliability of the results obtained using the ARDL model. The results of the CUSUM of Squares test showed that the residual variance and parameters of the regression model are stable over time. This confirms the statistical reliability of the results obtained using the ARDL model. According to the research results, energy production and energy consumption indicators have a stable positive impact on industrial development. Therefore, the development of energy infrastructure and increasing energy efficiency is an important strategic factor in ensuring long-term sustainable growth of the industrial sector.

Conclusions

In conclusion, the results of the econometric analysis showed that energy production and consumption indicators are important determinants of industrial value-added growth. The long-term dependence determined by the ARDL model and confirmed by the CUSUM and CUSUMSQ tests ensures the reliability of the model stability results. Based on this, the development of energy infrastructure, increasing energy efficiency, and the efficient use of energy resources is an important strategic direction in ensuring the sustainable development of the industrial sector.

As a result, the modernization of the energy system, the expansion of electricity generation capacities, and the attraction of investments in the energy sector will serve to increase the long-term competitiveness of Uzbekistan's industry. The results of this study are important for making scientifically based decisions in the formation of energy and industrial policy.

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