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FORECASTING ENERGY CONSUMPTION IN UZBEKISTAN

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Abstract: One of the most important factors of economic development is, undoubtedly, energy. Efficient use of energy sources is among the essential tasks we must implement in all areas of life. Using econometric models to assess the role of energy sources in economy of a country helps evaluate their significance in energy distribution, household consumption, and the technological development of enterprises. For this purpose, in our article, we constructed an ARDL model to investigate the impact of energy consumption on economic growth in Uzbekistan. Both long-term and short-term effects were calculated, and forecast values were obtained. According to the AIC and BIC criteria, the model that best fits the collected data was identified, and the ARDL(2, 2, 0, 0) model was selected as the optimal model. The results of the bounds test indicated the existence of a long-term cointegration relationship. The consumption of petroleum products has a negative and statistically significant effect on economic growth ($p < 0.01$), while electricity generation has a positive effect ($p < 0.05$). Although the natural gas consumption variable shows a negative effect in the long run, it is not statistically significant in the short-run dynamics. The conclusion drawn from the results is that promoting electricity generation and reducing dependence on petroleum products in energy policy will contribute to stabilizing economic growth.

ПРОГНОЗИРОВАНИЕ ПОТРЕБЛЕНИЯ ЭНЕРГИИ В УЗБЕКИСТАНЕ

Аннотация: Одним из важнейших факторов экономического прогресса, безусловно, является энергия. Эффективное использование источников энергии-одна из задач, которую мы должны применять во всех сферах нашей жизни. Использование эконометрических моделей для оценки места энергоресурсов в экономике страны помогает оценить их значимость для распределения энергии в стране, потребления населением, технического прогресса предприятий. С этой целью в данной статье при исследовании влияния потребления энергии в Узбекистане на экономический рост была построена модель ARDL, рассчитаны долгосрочные и краткосрочные эффекты и получены прогнозные значения. По критерию AIC, Bic были определены журналы моделей, которые лучше всего соответствовали собранным данным, и в качестве оптимальной модели была выбрана модель ARDL(2, 2, 0, 0). Bounds test результаты показали, что эта модель имеет долгосрочную коинтеграцию. Потребление нефтепродуктов оказывает отрицательное и статистически значимое влияние на экономический рост (P < 0,01), в то время как производство электроэнергии оказывает положительное влияние (p < 0,05). Хотя переменная потребления природного газа отрицательно влияет на долгосрочные отношения, она не имеет статистической значимости в краткосрочной динамике. Из результатов был сделан вывод, что стимулирование производства электроэнергии в энергетической политике и снижение зависимости от нефтепродуктов служат для стабилизации экономического роста.

O'ZBEKISTONDA ENERGIYA RESURSLARI SARFINING IQTISODIY O'SISHGA TASIRINI ARDL MODELI ORQALI EKONOMETRIK TADQIQ QILISH

Annotatsiya: Iqtisodiy taraqqiyotning eng muhim omillaridan biri bu albatta energiya hisoblanadi. Energiya manbalaridan samarali foydalanish hayotimizning barcha sohalarida qo'llashimiz kerak bo'lgan vazifalarimizdan biridir. Energiya manbalarining mamlakat iqtisodiyotida o'rnini baholash uchun ekonometrik modellardan foydalanish mamlakatda energitik taqsimot, aholi iste'moli, korxonalarning texnik taraqqiyoti uchun qanday ahamiyatli ekanligini baholashga yordam beradi. Shu maqsadda ushbu maqolamizda O'zbekistonda energiya iste'molining iqtisodiy o'sishga tasirini tadqiq qilishda ARDL modeli tuzilib, uzoq va qisqa muddatli tasirlar hisoblab chiqildi hamda prognoz qiymatlari olindi. AIC, BIC kreteriyasiga ko'ra to'plangan ma'lumotlarga eng mos tushgan model loglari aniqlandi va ARDL(2, 2, 0, 0) modeli optimal model sifatida tanlab olindi. Bounds test natijalar ushbu model uzoq muddatli kointegratsiya mavjudligini ko'rsatdi. Neft mahsulotlari iste'moli iqtisodiy o'sishga salbiy va statistik jihatdan ahamiyatli ta'sir ko'rsatmoqda ($p < 0.01$), Elektr ishlab chiqarish esa ijobiy ta'sirga ega ($p < 0.05$). Tabiiy gaz iste'moli o'zgaruvchisi uzoq muddatli munosabatlarda salbiy ta'sir ko'rsatsa-da, qisqa muddatli dinamikada statistik ahamiyatga ega emas. Natijalardan xulosa shu bo'ldiki, energetika siyosatida elektr ishlab chiqarishni rag'batlantirish va neft mahsulotlariga bog'liqlikni kamaytirish iqtisodiy o'sishni barqarorlashtirishga xizmat qilishini ko'rsatadi.

INTRODUCTION

In recent decades, the use of energy resources has become one of the strategic directions of economic policy on a global scale. Energy is increasingly being recognized as a key factor of production in all sectors of the economy, including production, transport, services, and the daily activities of households. At the same time, the issue of the relationship between energy consumption and economic growth is of central importance for countries in developing sustainable development strategies. The Republic of Uzbekistan is also paying attention to the energy sector in ensuring its economic growth. In recent years, the acceleration of modernization and industrialization processes in the economy has sharply increased energy consumption. However, the fact that the main part of energy resources is made up of traditional sources such as coal, natural gas, and oil creates a situation that requires a complex balance between economic growth and environmental sustainability. There are also problems such as external risks associated with energy imports, low energy efficiency, technological obsolescence in production, and energy losses, which directly or indirectly affect economic growth. In this context, it is of great importance to determine how energy consumption affects economic growth indicators, and to study the short- and long-term characteristics of this relationship on a statistical basis. In particular, assessing this issue using an economic model based on time series data is of great practical importance for policy development and decision-making in the energy sector. From this point of view, determining the cause-and-effect relationship between energy consumption and economic growth using the ARDL (Autoregressive Distributed Lag) model is a scientific and practical issue in the conditions of Uzbekistan. Based on this need, this study aims to assess the impact of energy consumption on economic growth in the Republic of Uzbekistan using the ARDL model. This is intended to identify the level of energy dependence, the possibilities for optimizing energy consumption, and the necessary strategic directions for ensuring sustainable economic development.

The global conference on "New and Renewable Energy" held by the United Nations in 1980 outlined the foundations of a modern approach to renewable energy sources. It noted that the concept of "new energy" means the modernization of traditional renewable sources based on new technologies and advanced materials and their use in a modern way. This approach is based on the principles of environmental sustainability and energy security (United Nations, 1980). To date, renewable energy sources based on unlimited natural resources, such as solar, wind, biomass, wave energy, geothermal heat, hydrogen and nuclear energy, are recognized as sustainable alternatives to traditional, environmentally harmful fossil fuel resources (Owusu & Asumadu-Sarkodie, 2016). They play an important role in developing sustainable energy development strategies. A clear distinction between renewable energy and new energy is essential for developing sustainable energy policies. As can be seen from the definitions, renewable energy sources, such as solar, wind, or geothermal energy, often fall under the category of new energy. However, not all new energy sources are necessarily renewable. For example, nuclear energy, despite its great potential for energy production, cannot be considered fully renewable due to radioactive waste (Panwar, Kaushik, & Kothari, 2011). In general, new energy sources are environmentally friendly, widely available, andand is an important resource in ensuring long-term energy security (REN21, 2023). These resources are considered a key factor in reducing carbon emissions and ensuring economic and energy sustainability on a global scale. Currently, many scientific studies are aimed at analyzing the complex relationship between energy consumption, economic growth and environmental pollution. One of the most important theoretical foundations in this direction is the concept of the Environmental Kuznets Curve (EKC). According to this theory, the level of pollution increases in the early stages of economic development, but after reaching a certain level, pollution decreases as a result of the introduction of sustainable technologies and political reforms (Grossman & Krueger, 1995; Dinda, 2004; Apergis & Payne, 2009; Shahbaz et al., 2015). The classic model of the EKC theory oversimplifies this complex relationship. That is, it sufficiently takes into account important factors such as the level of technological development, the structure of production and consumption, the severity of environmental policies, the openness of international trade, and the level of environmental demand of society (Stern, 2004). Therefore, modern research is trying to enrich this theory with empirical models. In recent years, the composition of energy types, the level of technological development, demographic changes, foreign direct investment (FDI), and carbon dioxide (CO_2) emissions have been widely analyzed as the main factors affecting economic growth. Modern econometric approaches, in particular, the Autoregressive Distributed Lag (ARDL) and Vector Error Correction Model (VECM) methodologies, are used to study the complex relationship between these factors (Pesaran et al., 2001; Engle & Granger, 1987). Empirical analyses conducted in the case of Saudi Arabia have shed light on the short- and long-term relationships between these factors. The results of the study show that renewable and non-renewable energy sources, population growth, FDI inflows, and energy exports positively stimulate economic growth (Alkhathlan & Javid, 2013; Alshehry & Belloumi, 2015). However, technological progress can have negative effects in some cases, due to a decrease in production efficiency or an increase in technological unemployment (Sadorsky, 2011). It is also possible that increased CO_2 emissions will put a negative pressure on economic resources in the long run (Farhani & Shahbaz, 2014). These results imply that a balanced approach to energy policy is necessary to achieve sustainable economic development, in which environmental sustainability, technological innovation, and investment policies must be pursued in harmony. In recent years, the complex interactions between economic growth, macroeconomic stability, and environmental variables have become a central topic on the global political and scientific agenda. This relationship is particularly relevant for countries like Singapore, which is a small country with a technologically and financially advanced economy. The effects of FDI, inflation, exchange rate, renewable energy use, trade openness, and innovation on gross domestic product (GDP) growth have been studied across many countries (Omri et al., 2014; Mert & Caglar, 2020), but a comprehensive analysis of these factors in the specific socio-economic context of Singapore has not yet been fully explored. To address this gap, some studies have sought to identify the short- and long-run relationships between these factors using the ARDL (Autoregressive Distributed Lag) approach. This model is an effective tool for analyzing long-run equilibrium between variables, especially for developed economies with small sample sizes (Pesaran et al., 2001). In addition, the interaction between the stock market and energy consumption has become a priority research area at the intersection of energy policy and financial economics. For the GCC (Gulf Cooperation Council) countries, 1971–Panel studies conducted between 2011 and 2021 have found that stock market performance, market capitalization, and stock trading volume have significant effects on oil and electricity consumption (Al-Mulali & Sab, 2012; Sadorsky, 2012). Long-term empirical results show that stock market trading volume is a factor that increases electricity consumption, while short-term approaches show that this effect does not exist. These results indicate the need for a deeper analysis of energy consumption and financial sector integration, as well as the need to use stock market mechanisms in developing sustainable economic policies. In particular, encouraging investment in energy-efficient technologies and imposing financial constraints on projects that consume too much energy are seen as important strategic tools. The implementation of such measures will pave the way for financial support for sustainable energy policies through the stock market (Ghosh & Kanjilal, 2016). In addition, the problem of effective and sustainable management of water resources in arid and semi-arid regions has become a pressing issue today against the backdrop of global climate change. The interrelationship between water scarcity and food security is particularly strong in the case of Central Asia and the Middle East (Wada et al., 2011; Allan, 2003). The use of ARDL and VECM models to empirically analyze these complex relationships is becoming increasingly popular. In a study conducted on the case of the Finnish economy over the period 1990–2022, the impact of these factors on CO_2 emissions was estimated using the Fourier-augmented ARDL (FARDL) model. The results of the study show that the use of renewable energy and innovative patenting activities play a significant positive role in reducing CO_2 emissions, especially the long-term impact is stronger (Saadaoui et al., 2023). Short-term analyses also confirm that REN and PA have a negative and statistically significant impact on CO_2 emissions. This indicates that technological development and investment in green energy are important factors in ensuring environmental protection (Saadaoui et al., 2023). Also, the lack of a significant impact of economic growth on CO_2 emissions in the short term indicates some degree of decoupling, that is, a weakening of the relationship between economic development and environmental degradation. This is considered an important strategic opportunity for environmentally sustainable development (Zafar et al., 2019). These results clearly demonstrate the need for policies aimed at stimulating innovation and increasing investment in renewable energy to reduce carbon dioxide emissions in the long term. In particular, public policies that support technological innovation are of paramount importance for achieving green growth (Bilgili et al., 2016). Furthermore, the interrelationships between clean energy, pollution reduction, and economic growth are particularly relevant in the context of the Gulf Cooperation Council (GCC) member states.In this oil-rich but sustainable region, studies (1980–2019) have shown that energy production has a positive short- and long-term impact on economic growth, while energy consumption has a significant impact mainly in the long-term, based on the ARDL model (Alola et al., 2021). This suggests the need to diversify energy policies and accelerate the transition to innovative technologies. While short-term analyses do not clearly show a statistical relationship between energy consumption and economic growth, Granger causality analyses have revealed a significant causality between energy activities and urbanization and economic growth. In a study conducted in the case of Somalia, the long-term impact of FDI on renewable energy consumption was analyzed using the ARDL model based on data from 1990–2019. The results show that FDI flows have a positive impact on environmental protection by financing sustainable energy technologies (Ali et al., 2022). Therefore, channeling foreign investment into innovative and green technologies can become a key strategic tool for accelerating the transformation of the energy sector in developing countries. In particular, it is important to pursue active policies to attract foreign investment in the REN sector, combine economic growth with environmental sustainability, and facilitate access to green technologies through trade openness. In this regard, it is urgent for governments to develop measures to ensure a progressive regulatory environment, ensure investment security, and attract technologies that meet environmental standards (Sadorsky, 2010). It is also important to note that the available analyses are based on annual panel data and may not fully reflect short-term changes. Therefore, it is recommended that future studies conduct analyses based on high-frequency (monthly or quarterly) data, as well as use PVAR, QARDL, or NARDL models that allow for a better understanding of the dynamic causal relationships between variables (Anton & Nucu, 2020).

METHODOLOGY

In this article, we use Autoregressive Distributive Lags (ARDL) to identify the short- and long-term relationship between energy resource consumption and economic growth variables in Uzbekistan. This approach was developed by Pesaran and Shin (1999) and Pesaran, Shin, and Smith (2001), and is distinguished by its advantages such as the possibility of variables in the model being I(0) or I(1), providing reliable estimates even for small samples, and being especially suitable for time series. To build an ARDL($p, q_1, q_2, ..., q_k$) model, we estimated the relationship between variables expressed in natural logarithm form, such as ln_GDPpp (gross domestic product per capita), ln_EG (electricity generation), ln_CoC (coal consumption), ln_NGC (natural gas consumption), and ln_OC (oil consumption). The general equation of the ARDL model is as follows:

$$\Delta \ln GDPpp_t = \alpha_0 + \sum_{i=1}^{p} \beta_i \Delta \ln GDPpp_{t-i} + \sum_{j=0}^{q_1} \gamma_j \Delta \ln EG_{t-j} + \sum_{k=0}^{q_2} \delta_k \Delta \ln CoC_{t-k} + \sum_{l=0}^{q_3} \phi_l \Delta \ln NGC_{t-l} + \sum_{m=0}^{q_4} \theta_m \Delta \ln OC_{t-m} + \lambda_1 \ln GDPpp_{t-1} + \lambda_2 \ln EG_{t-1} + \lambda_3 \ln CoC_{t-1} + \lambda_4 \ln NGC_{t-1} + \lambda_5 \ln OC_{t-1} + \varepsilon_t$$

Here: - first-order difference operator; - free term; - short-term dynamic coefficients; from to - long-term equation coefficients; - random error term. In the first stage of econometric model building, the order of integration of variables is determined. For this, ADF (Augmented Dickey-Fuller) or PP (Phillips-Perron) tests are used. If the variable is stationary, then all variables can be I(0) or I(1), but not I(2) to use the ARDL model. In the second stage, the optimal lag length of the model is determined using the Akaike (AIC), Schwartz (BIC), or Hannan-Quinn (HQIC) criteria. The model with the lowest value is selected. The third stage (Bounds Test) A bounds test is performed to determine the presence of long-term dependence. The F-statistic is compared with the lower and upper bounds developed by Pesaran et al. (2001). If F > upper bounds H0 is rejected (there is a relationship). If F < lower bounds H0 is not rejected (there is no relationship). If F is in the middle, the result is uncertain. In the fourth step, we performed the Long-run equation estimation. If cointegration is detected by the bounds test, the following long-run equation is estimated:

$$\ln GDPpp_t = \alpha_0 + \sum_{j=0}^{q_1} \beta_j \ln EG_{t-j} + \sum_{k=0}^{q_2} \gamma_k \ln CoC_{t-k} + \sum_{l=0}^{q_3} \delta_l \ln NGC_{t-l} + \sum_{m=0}^{q_1} \phi_m \ln OC_{t-m} + u_t$$

In the fifth step, we performed short-run dynamics estimation (ECM). Once the cointegration is determined, the Error Correction Model is constructed as follows:

$$\Delta \ln GDPpp_t = \alpha_0 + \sum_{i=1}^{p-1} \beta_i \Delta \ln GDPpp_{t-i} + \sum_{j=0}^{q_1-1} \gamma_j \Delta \ln EG_{t-j} + \sum_{k=0}^{q_2-1} \delta_k \Delta \ln CoC_{t-k} + \sum_{l=0}^{q_3-1} \phi_l \Delta \ln NGC_{t-l} + \sum_{m=0}^{q_1-1} \theta_m \Delta \ln OC_{t-m} + \psi ECM_{t-1} + \varepsilon_t$$

Here: - is the error from the long-run equation; - is the coefficient representing the rate of return to equilibrium, which is usually negative and statistically significant. At the sixth stage, we need to perform Diagnostic tests. To ensure the reliability of the model, the following diagnostic tests are performed: Breusch-Godfrey LM test for serial correlation, Breusch-Pagan-Godfrey test for heteroskedasticity, Jarque-Bera test for normal distribution of deviations, Stability is assessed using CUSUM and CUSUMQ graphs.

ANALYSIS AND RESULTS

This article uses data on electricity production, coal consumption, natural gas consumption and oil consumption from the World Bank's World Energy Statistical Review website for the Republic of Uzbekistan for the period 1990-2024. Before evaluating the ARDL model, it is necessary to check the stationarity of each variable in the time series. For this purpose, unit root tests were used in this study. In particular, the results of unit root tests for analyzing the stationarity of variables using the ADF (Augmented Dickey–Fuller) test are presented in Table 1.

Table 1.

Results of unit root tests for energy resource indicators in the Republic of Uzbekistan

O'zgaruvchi	t qiymat	1% chegara qiymati	5% chegara qiymati	p-qiymat	xulosa
ln_GDPpp	-1.339	-4.352	-3.588	0.8781	no-statsionar
ln_EG	-0.542	-4.352	-3.588	0.9817	no-statsionar
ln_CoC	-2.773	-4.352	-3.588	0.2071	no-statsionar
ln_NGC	-2.901	-4.352	-3.588	0.1620	no-statsionar
ln_OC	-0.658	-4.352	-3.588	0.9758	no-statsionar
1-ayirma olingandan so'ng					
d_ln_GDPpp	-2.883	-4.362	-3.592	0.1681	no-statsionar
d_ln_EG	-7.157	-4.362	-3.592	0.0000	statsionar'
d_ln_CoC	-7.450	-4.362	-3.592	0.0000	statsionar'
d_ln_NGC	-6.137	-4.362	-3.592	0.0000	statsionar'
d_ln_OC	-6.351	-4.362	-3.592	0.0000	statsionar'

According to the results, GDP, electricity (EG), coal consumption (CoC), natural gas consumption (NGC), and oil consumption (OC) in their natural logarithms were found to be non-stationary at the first level, as their t-statistics were smaller than the critical values at the 1% and 5% confidence levels, and their p-values were higher than 0.05. This means that these variables have first-level integrality (I(1)). After taking the first difference, the ADF test statistics for the variables were lower than –6, which was much lower than the 1% level. Their p-value was also 0.0000, confirming that these variables became stationary after the first difference. However, the GDP variable did not fully meet the stationarity requirements with a statistical value of –2.883 and a p-value of 0.1681. This variable may require a possible second-order differentiation or may indicate the presence of a structural break. In general, all variables, except GDP per capita, have become stationary after the first difference, which means that the I(1) requirement required for ARDL or cointegration analysis is met.

Table 2 shows several selection criteria used to determine the optimal lag level of the VAR (Vector Autoregression) model for the endogenous variables included in the model: Akaike Information Criterion (AIC), Schwarz Criterion (SC), Hannan-Quinn Criterion (HQ), and the Final Prediction Error (FPE) and Likelihood Ratio (LR) tests.

Table 2

Selecting the Optimal Lag Level for the VAR Model

Lag	LogL	LR	FPE	AIC	SC	HQ
0	73.39186	NA	9.81e-08	-4.785646	-4.597053	-4.726581
1	170.8965	161.3870	3.60e-10	-10.40666	-9.463695*	-10.11133
2	191.2945	28.13514*	2.85e-10*	-10.70997*	-9.012633	-10.17838*

According to the results, lag(2) is recommended as the optimal lag level by most of the criteria. According to the LR test, lag(2) has the highest value (28.13514) and is found to be statistically significant at the 5% confidence level. FPE (Final Prediction Error) preferred lag(2) with the smallest value (2.85e-10). According to the Akaike Information Criterion (AIC), it gave the lowest value of –10.70997, indicating lag(2) as the optimal one. Similarly, the Hannan-Quinn Criterion (HQ) showed the lowest value (–10.17838) for lag(2). Only the Schwarz Criterion (SC) preferred lag(1), indicating lag(1) as the most appropriate with a value of –9.463695. Based on the analysis of these criteria, lag(2) was selected as the optimal lag level because it has the advantage in terms of AIC, FPE, HQ, and LR criteria. The SC criterion's recommendation of lag(1) suggests a simplified version of the model, but it is not covered by the other criteria. Therefore, it is considered reasonable to use lag(2) in the subsequent ARDL model building and analysis stages.

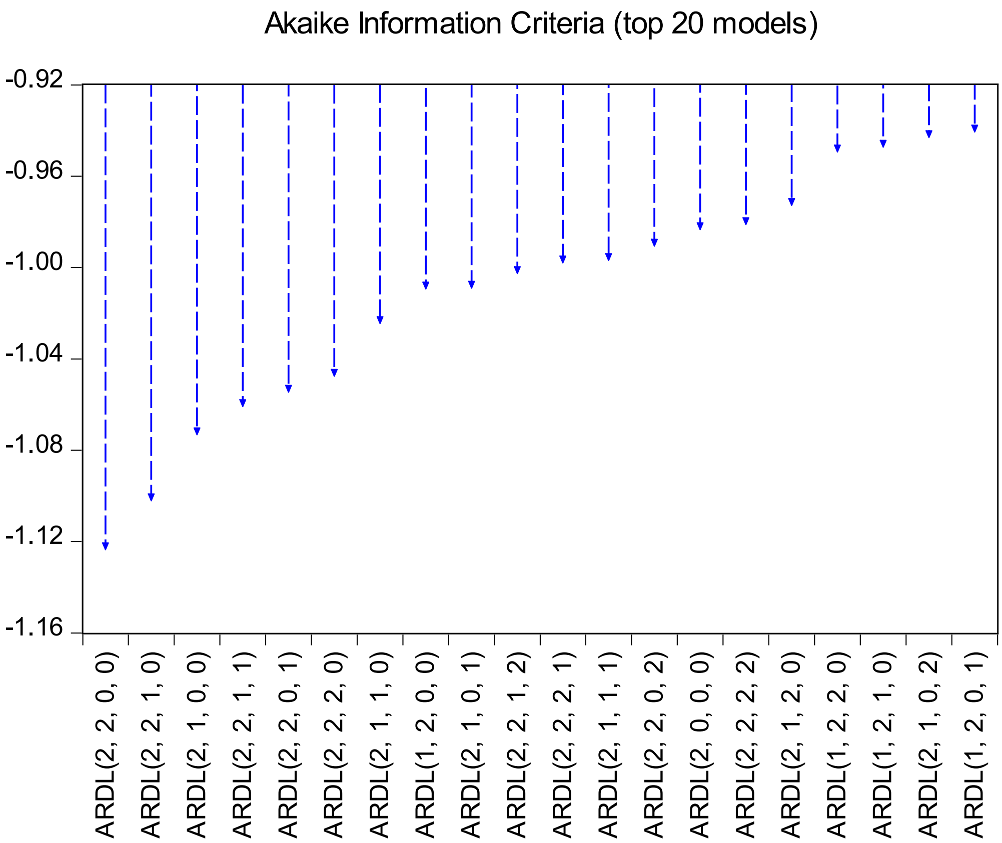

Figure 1 - The Akaike Information Criterion (AIC) criterion was used to select the ARDL (AutoRegressive Distributed Lag) model. The graph above shows the top 20 models with the lowest AIC values. The vertical axis shows the AIC values, and the horizontal axis shows the structures (lag levels) of the corresponding ARDL models. According to the analysis results: The lowest AIC value is around –1.14, and the ARDL(2, 2, 0, 0) model was found to be the most appropriate. The next best-fitting models after this model are ARDL(2, 2, 1, 0), ARDL(2, 2, 0, 1) and ARDL(2, 2, 1, 1). These results show that the model is best represented by second-order lags for the first two variables, and zero or first-order lags for the remaining variables. The selection of the ARDL(2, 2, 0, 0) model as the most optimal model according to AIC means that this model minimizes the forecasting error and best represents the lagged relationship between economic indicators through its dynamic structure. Therefore, the use of the ARDL(2, 2, 0, 0) model in the subsequent stages of empirical analysis is in accordance with economic logic and statistical criteria.

Table 3

Results of the ARDL(2, 2, 0, 0) model

Variable	Coefficient	Std. Error	t-Statistic	Prob.*
LN_GDPPP(-1)	0.920749	0.219395	4.196767	0.0004
LN_GDPPP(-2)	-0.352571	0.171612	-2.054467	0.0526
LN_NGC	0.192902	0.549570	0.351004	0.7291
LN_NGC(-1)	-0.730680	0.587000	-1.244769	0.2269
LN_NGC(-2)	-0.978276	0.599535	-1.631724	0.1176
LN_OC	-1.083192	0.317992	-3.406345	0.0027
LN_EG	0.725601	0.276309	2.626049	0.0158
C	-0.710566	0.736712	-0.964509	0.3458

R-squared	0.972186	Mean dependent var	7.169401
Adjusted R-squared	0.962915	S.D. dependent var	0.639493
S.E. of regression	0.123150	Akaike info criterion	-1.121880

Sum squared resid	0.318483	Schwarz criterion	-0.744695
Log likelihood	24.26726	Hannan-Quinn criter.	-1.003750
F-statistic	104.8610	Durbin-Watson stat	2.459191
Prob(F-statistic)	0.000000		

In order to determine the long-term and short-term relationships, the ARDL model was evaluated in Table 3. Based on the Akaike Information Criterion (AIC), the ARDL(2, 2, 0, 0) structure was found to be the most optimal out of 54 combinations. In the model, the relationship was analyzed through the dynamic relationships between the LN_GDPPP (Gross Domestic Product per capita) variable and the LN_NGC (Coal Consumption), LN_OC (Oil Consumption) and LN_EG (Total Energy Expenditure) variables. Short-term effects) The model results showed that: The coefficient of LN_GDPPP(-1) is 0.9207, which is highly significant based on the t-statistic (4.20) and p-value (0.0004). This means that the economic growth rate of the previous year has a strong positive effect on the current situation. The coefficient of LN_GDPPP(-2) is negative (–0.3526), indicating that there is a change in the lagged effect. Its p-value (0.0526) is marginally significant. LN_OC (oil consumption) has a negative and statistically significant effect on economic growth ($\beta = -1.0831$, $p = 0.0027$), indicating that oil dependence reduces growth rates. LN_EG (energy expenditure) has a positive and significant effect on economic growth ($\beta = 0.7256$, $p = 0.0158$), indicating that investment in energy stimulates economic activity. LN_NGC and its lagged values are not statistically significant, but their signs (especially 0.9783) indicate a negative impact for economic analysis. The model has a high overall fit: $R^2 = 0.972$, which explains more than 97% of the variance explained by the model. The F-statistic = 104.86 and Prob(F-stat) = 0.0000 indicate that the model is statistically significant overall. The Durbin-Watson statistic = 2.459 indicates that there is no autocorrelation problem in the residuals. The Akaike Information Criterion (AIC) = –1.1219 — this value once again confirms that this model is the most optimal choice in terms of AIC. The results of the ARDL(2, 2, 0, 0) model reveal a significant impact of energy-related variables on economic growth. While the negative impact of oil consumption indicates the need for diversification of energy resources, the positive impact of total energy expenditure confirms the importance of energy investments as a mechanism for stimulating economic growth.

The graph in Figure 2 shows the actual (red), estimated (green) values, and residuals (blue) of the ARDL(2,2,0,0) model. The actual and estimated values of the model are very close to each other, which indicates that the ARDL model has a strong adaptive capacity. Only in 2018 was a negative deviation (about -3.5) observed, during which there was a significant difference between the expected value of the model and the actual value. This indicates the presence of possible shocks or variables not included in the model. In addition, there is no clear sign of autocorrelation in the residuals, which is also confirmed by the Durbin-Watson statistic (2.459). This graph shows that the model predicts the actual values with high accuracy and that the residuals are generally randomly distributed. This indicates that the probability of error in the model is low, and also that the forecasting capabilities of the ARDL model are reliable.

Table 4

Results of Long-run form and Bounds test based on the ARDL(2,2,0,0) model

Conditional Error Correction Regression

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-0.710566	0.736712	-0.964509	0.3458
LN_GDPPP(-1)*	-0.431822	0.109155	-3.956056	0.0007
LN_NGC(-1)	-1.516054	0.668091	-2.269234	0.0339
LN_OC**	-1.083192	0.317992	-3.406345	0.0027
LN_EG**	0.725601	0.276309	2.626049	0.0158
D(LN_GDPPP(-1))	0.352571	0.171612	2.054467	0.0526
D(LN_NGC)	0.192902	0.549570	0.351004	0.7291
D(LN_NGC(-1))	0.978276	0.599535	1.631724	0.1176

Levels Equation

Case 3: Unrestricted Constant and No Trend

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LN_NGC	-3.510829	1.259533	-2.787404	0.0110
LN_OC	-2.508420	0.411332	-6.098287	0.0000
LN_EG	1.680324	0.469082	3.582153	0.0018

EC = LN_GDPPP - (-3.5108*LN_NGC -2.5084*LN_OC + 1.6803*LN_EG)

F-statistic	3.929152	5%	3.23	4.35
t-Bounds Test		Null Hypothesis: No levels relationship		

Test Statistic	Value	Signif.	I(0)	I(1)
t-statistic	-3.956056	5%	-2.86	-3.78

In the next stage of the econometric analysis, the Bounds test proposed by Pesaran et al. (2001) was used to determine the presence of long-run dependence in the ARDL(2, 2, 0, 0) model. The analysis was conducted in Case 3 (free variable: constant, trend: non-existent). The long-run dependence equation is defined as follows:

EC =LN_GDPPP −(−3.5108⋅ LN_NGC −2.5084⋅ LN_OC +1.6803⋅ LN_EG)ECt =LN_GDPPPt−(−3.5108⋅ LN_NGCt −2.5084⋅ LN_OCt +1.6803⋅ LN_EGt)

The following results were observed for this equation: Coal consumption (LN_NGC) has a negative impact on GDP per capita in the long run ($\beta = -3.5108$, $p = 0.0110$). Oil consumption (LN_OC) is also negative and statistically significant ($\beta = -2.5084$, $p < 0.01$), indicating the inhibitory effect of dependence on traditional energy sources on economic growth. Energy costs (LN_EG) have a positive and significant effect ($\beta = 1.6803$, $p = 0.0018$), indicating that energy investments can stimulate economic growth. The existence of a long-run equation was tested using the ARDL bounds test: F-statistic = 3.929, which is between the 10% (I(1): 3.77) and 5% (I(1): 4.35) thresholds. This represents an inconclusive region. However, the t-statistic = –3.956, which is also below the upper limit of the 5% confidence interval (–3.78). This result confirms the existence of a long-run relationship according to the t-Bounds test. Therefore, although the F-statistic does not provide a definitive conclusion, it is considered that there is a long-run cointegrating relationship based on the t-Bounds test. These results show that Uzbekistan's economic growth is significantly dependent on energy-related variables in the long run. While traditional resources (coal and oil) act as a drag on growth, energy costs (investments) act as a driving force. This highlights the need for a sustainable energy policy and diversification of the resource mix.

Table 5

Error Correction Model (ECM) results

ECM Regression

Case 3: Unrestricted Constant and No Trend

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-0.710566	0.175403	-4.051054	0.0006
D(LN_GDPPP(-1))	0.352571	0.139613	2.525354	0.0197
D(LN_NGC)	0.192902	0.437565	0.440852	0.6638
D(LN_NGC(-1))	0.978276	0.525221	1.862600	0.0766
CointEq(-1)*	-0.431822	0.101890	-4.238141	0.0004

R-squared	0.569137	Mean dependent var	0.049459
Adjusted R-squared	0.497327	S.D. dependent var	0.162478
S.E. of regression	0.115196	Akaike info criterion	-1.328777
Sum squared resid	0.318483	Schwarz criterion	-1.093036
Log likelihood	24.26726	Hannan-Quinn criter.	-1.254946
F-statistic	7.925545	Durbin-Watson stat	2.459191
Prob(F-statistic)	0.000320		

F-statistic	3.929152	5%	3.23	4.35
t-statistic	-4.238141	5%	-2.86	-3.78

Within the ARDL(2,2,0,0) model, an error correction model (ECM) was built to identify short-term dynamics and assess deviations from long-term equilibrium. The ECM regression was estimated on the first difference of the LN_GDPpp variable (i.e., the economic growth rate). The results show that the error correction coefficient in the model (CointEq(-1)) is –0.4318, which is highly statistically significant at the 1% level (p = 0.0004). This negative and significant value means that any deviation from long-term equilibrium is corrected by 43% of its value every year. This represents the speed of return to equilibrium in the economic system and is considered one of the main advantages of the ARDL model. Among the short-term effects, the first-level lagged value of the LN_GDPpp(-1) variable has a positive and statistically significant effect on economic growth (β = 0.3526, p = 0.0197). This indicates that the growth rates of the previous period have a significant effect on the growth of the current period. The LN_NGC variable (coal consumption) and its first-level lagged value are not statistically significant in the short term (p = 0.6638 and p = 0.0766), but the p-value of the LN_NGC(-1) value is close to the 10% level. This indicates that the short-term effect of coal consumption may be potentially significant on economic growth. The overall statistical results of the model demonstrate high quality. F-statistic = 7.93, p = 0.0003 indicates that the model is generally significant. R^2 = 0.569, Adj. R^2 = 0.497, which means that almost 57% of the variance in economic growth can be explained. Durbin-Watson statistic = 2.459 indicates that there is no autocorrelation in the residuals. In addition, the result of the t-Bounds test (t-stat = –4.2381) is below the 1% confidence interval, which confirms the presence of a long-term cointegrating relationship. The results of the ECM model show that economic growth is significantly dependent on energy variables in the long run, and in the short run tends to an equilibrium state through a self-reversing mechanism. The stability and statistical significance observed in the model indicate that the ARDL model is a reliable tool for dynamic analysis.

Table 6

Testing autocorrelation in residuals: Breusch–Godfrey LM test results

F-statistic	3.131624	Prob. F(2,19)	0.0668
Obs*R-squared	7.189661	Prob. Chi-Square(2)	0.0275

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LN_GDPPP(-1)	0.525571	0.294757	1.783066	0.0906
LN_GDPPP(-2)	-0.376786	0.224144	-1.680999	0.1091
LN_NGC	0.271173	0.513592	0.527994	0.6036
LN_NGC(-1)	-0.093558	0.538821	-0.173634	0.8640
LN_NGC(-2)	0.477435	0.579057	0.824506	0.4199
LN_OC	0.336659	0.320970	1.048878	0.3074
LN_EG	-0.270990	0.275894	-0.982226	0.3383
C	0.201851	0.680349	0.296688	0.7699
RESID(-1)	-0.777933	0.324421	-2.397915	0.0269
RESID(-2)	-0.397721	0.236410	-1.682335	0.1089

R-squared	0.247919	Mean dependent var	-1.18E-15
Adjusted R-squared	-0.108329	S.D. dependent var	0.106651
S.E. of regression	0.112279	Akaike info criterion	-1.268861
Sum squared resid	0.239525	Schwarz criterion	-0.797380
Log likelihood	28.39848	Hannan-Quinn criter.	-1.121199
F-statistic	0.695916	Durbin-Watson stat	2.112120
Prob(F-statistic)	0.704859		

In order to check the presence of autocorrelation in the residuals of the regression model built on the basis of the ARDL(2,2,0,0) model, the Breusch-Godfrey Serial Correlation LM test was performed. This test is an effective tool for determining whether there is lagged autocorrelation in the residuals. According to the results of the LM test, the F-statistic = 3.13, p-value = 0.0668, which cannot reject the presence of autocorrelation at the 5% confidence level. The R-squared = 7.19, Chi-square p-value = 0.0275, which is statistically significant at the 5% level. This result indicates the presence of second-order autocorrelation. In the test, lags 1 and 2 of the residuals in the model are included in the regression, and their t-statistic for RESID(-1) is –2.39 (p = 0.0269), which indicates a significant effect of the lag. However, the overall F-statistic (for all variables included in the model) is 0.6959 (p = 0.7049), indicating that the model is not statistically significant on its own, but that the problem is being detected by specialized tests for autocorrelation (LM and Chi-square). The results of the Breusch–Godfrey test indicate the presence of low-level, but potentially statistically significant, second-order autocorrelation in the residuals. This situation indicates the need to revise the model specification, add additional lags, or use solutions that mitigate autocorrelation.

Table 7

Analysis of Heteroskedasticity: Results of the Breusch–Pagan–Godfrey Test

F-statistic	1.019583	Prob. F(7,21)	0.4464
Obs*R-squared	7.355963	Prob. Chi-Square(7)	0.3928
Scaled explained SS	6.290693	Prob. Chi-Square(7)	0.5062

Variable	Coefficient	Std. Error	t-Statistic	Prob.

C	0.076356	0.120458	0.633878	0.5330
LN_GDPPP(-1)	-0.007423	0.035873	-0.206930	0.8381
LN_GDPPP(-2)	0.038049	0.028060	1.356010	0.1895
LN_NGC	0.003106	0.089859	0.034561	0.9728
LN_NGC(-1)	-0.055238	0.095979	-0.575519	0.5711
LN_NGC(-2)	0.145968	0.098028	1.489041	0.1513
LN_OC	0.061068	0.051994	1.174521	0.2533
LN_EG	-0.058440	0.045179	-1.293522	0.2099

R-squared	0.253654	Mean dependent var	0.010982
Adjusted R-squared	0.004872	S.D. dependent var	0.020185
S.E. of regression	0.020136	Akaike info criterion	-4.743673
Sum squared resid	0.008515	Schwarz criterion	-4.366488
Log likelihood	76.78326	Hannan-Quinn criter.	-4.625544
F-statistic	1.019583	Durbin-Watson stat	2.094995
Prob(F-statistic)	0.446359		

In order to assess the stability of variance (homoscedasticity) in the residuals of the ARDL(2,2,0,0) model, the Breusch-Pagan-Godfrey heteroscedasticity test was performed. In the test, the residual squares ($RESID^2$) were regressed on the independent variables and their lags. This approach allows us to determine the variability of the residual variance with respect to the variables in the model. The test results are as follows: F-statistic = 1.0196, p = 0.4464, which means that the null hypothesis (i.e., the presence of homoscedasticity) cannot be rejected at the 5% level of confidence. The values of $R^2 = 7.356$, p = 0.3928 and Scaled Explained SS = 6.291, p = 0.5062 also support the null hypothesis. The results of this test indicate that there is no heteroscedasticity in the residuals of the model. That is, the variance of the residuals does not have systematic changes relative to the independent variables, which strengthens the statistical stability of the model. Also, the independent variables (i.e., LN_GDPPP, LN_NGC, LN_OC, LN_EG and their lags) do not have a statistically significant effect on the regression results on the residual squares. This is also additional evidence of the absence of variance variability. Based on the Breusch–Pagan-Godfrey test, heteroscedasticity was not detected in the model residuals. This indicates that the estimated coefficients of the ARDL model are effective and unbiased. Analyses and forecasts based on the model results have a reliable statistical basis.

CONCLUSION

This study is aimed at econometric analysis of the impact of energy resource consumption on economic growth in the Republic of Uzbekistan, and the time series-based ARDL (Autoregressive Distributed Lag) model was used in this process. The study uses the following main variables in logarithmic form based on data from 1994–2024: gross domestic product per capita (ln_GDPpp), total energy expenditure (ln_EG), coal consumption (ln_NGC) and oil consumption (ln_OC). All stages of the analysis are based on strict statistical principles, and each model component is assessed using special diagnostic and accuracy criteria. First, the stationarity of the variables was checked using the ADF (Augmented Dickey-Fuller) test. The test results showed that not all variables are stationary, but after the first difference they achieved stationarity. This confirms that the necessary condition for using the ARDL model, which is to have mixed integrals I(0) and I(1), is met. Criteria such as AIC, SC, HQ, FPE were used to determine the optimal lag level in the VAR model. Most criteria (in particular, AIC and LR tests) showed that the second-order lag (lag(2)) was preferable, which served as the basis for the formation of the ARDL(2,2,0,0) model. The AIC value of the selected model (–1.12188) was the lowest and was determined as the optimal structure among 54 combinations. When the ARDL(2,2,0,0) model was evaluated, the short- and long-run effects of variables affecting economic growth were determined. The short-run analysis showed that oil consumption (OC) has a significant negative effect on growth ($\beta = -1.083$, $p < 0.01$), which is due to the instability of the energy composition,is explained by import dependence or low efficiency. On the other hand, energy costs (EG) have a positive effect ($\beta = 0.725$, $p < 0.05$), which indicates that investment in the energy sector serves to increase economic activity. Although the short-term effect of coal consumption (NGC) was statistically insignificant, its long-term effect was shown to be negative. The bounds test method was used in the analysis of long-term dependence. Although the F-statistic (3.929) value exceeded the I(1) value at the 10% confidence interval, it did not provide accuracy at the 5% interval. However, the t-Bounds test (t-stat = –4.238) was below the 1% critical value, strongly confirming the existence of a long-term cointegrating relationship. This indicates that there is a balanced long-term relationship between energy-related factors and economic growth. The correction of long-term deviations was also assessed through the Error Correction Model (ECM) regression. The error correction coefficient in the ECM is –0.4318 ($p < 0.01$), which means that deviations from long-term equilibrium are eliminated by an average of 43% each year. This indicator indicates a tendency for the economic system to quickly return to equilibrium. Among the short-term changes, only the GDPpp(-1) component ($p < 0.05$) is statistically significant, reflecting the positive inertial effect of past growth. The model forecast results also have a high level of accuracy. The predicted values are close to the real values, with low error rates (RMSE = 0.1165, MAPE = 1.28%) and Theil coefficient is 0.0081, with a result close to 0 indicating a high predictive ability of the model. The model is able to predict symmetrically and behaves within a 95% confidence interval. The reliability of the model was once again confirmed by diagnostic tests. Although the Breusch–Godfrey test revealed the possibility of a 2-order autocorrelation ($p = 0.0275$), this effect was weak and borderline, and the overall F-test was not statistically significant. The Breusch–Pagan–Godfrey heteroscedasticity test showed the stability of the variance of the model residuals ($p = 0.446$), which indicates the effectiveness of the model parameters. The final results show that energy-related factors in the Uzbek economy — especially energy costs — are an important component of economic growth. At the same time, dependence on oil and coal can slow down growth rates in the long run. The scientifically sound results obtained from the model can serve as a practical basis for developing energy policy. In particular, by diversifying the energy mix, attracting renewable sources, improving energy efficiency, and properly directing investments, Uzbekistan can ensure sustainable economic growth in the long run.

LIST OF REFERENCES

1. United Nations. (1980). United Nations Conference on New and Renewable Sources of Energy, Nairobi, 10–21 August 1981. New York: UN Department of Public Information.

2.Owusu, P. A., & Asumadu-Sarkodie, S. (2016). A review of renewable energy sources, sustainability issues and climate change mitigation. Cogent Engineering, 3(1), 1167990. https://doi.org/10.1080/23311916.2016.1167990

3.Panwar, N. L., Kaushik, S. C., & Kothari, S. (2011). Role of renewable energy sources in environmental protection: A review. Renewable and Sustainable Energy Reviews, 15(3), 1513–1524. https://doi.org/10.1016/j.rser.2010.11.037

4.Grossman, G. M., & Krueger, A. B. (1995). Economic growth and the environment. The Quarterly Journal of Economics, 110(2), 353–377.

5. Dinda, S. (2004). Environmental Kuznets Curve hypothesis: A survey. Ecological Economics, 49(4), 431–455.

6. Stern, D. I. (2004). The rise and fall of the Environmental Kuznets Curve. World Development, 32(8), 1419–1439.

7. Song, Y., Zheng, S., & Tong, L. (2008). An empirical test of the Environmental Kuznets Curve in China: A panel cointegration approach. China Economic Review, 19(3), 381–392.

8. Engle, R. F., & Granger, C. W. J. (1987). Co-integration and error correction: Representation, estimation, and testing. Econometrica, 55(2), 251–276.

9. Alkhathlan, K. A., & Javid, M. (2013). Energy consumption, carbon emissions and economic growth in Saudi Arabia: An aggregate and disaggregate analysis. Energy Policy, 62, 1525–1532.

10. Alshehry, A. S., & Belloumi, M. (2015). Energy consumption, carbon dioxide emissions and economic growth: The case of Saudi Arabia. Renewable and Sustainable Energy Reviews, 41, 237–247.
11. Sadorsky, P. (2011). Trade and energy consumption in the Middle East. Energy Economics, 33(5), 739–749.
12. Farhani, S., & Shahbaz, M. (2014). What role of renewable and non-renewable electricity consumption and output is needed to initially mitigate CO_2 emissions in the MENA region? Renewable and Sustainable Energy Reviews, 40, 80–90.
13. Tang, C. F., & Tan, B. W. (2014). The impact of energy consumption, income and foreign direct investment on carbon dioxide emissions in Vietnam. Energy, 79, 447–454.
14. Eyraud, L., Clements, B., & Wane, A. (2013). Green investment: Trends and determinants. Energy Policy, 60, 852–865.
15. Dinar, A., & Zilberman, D. (Eds.). (2012). The Economics of Water Quality. Springer Science & Business Media.
16. Alola, A. A., Bekun, F. W., & Sarkodie, S. A. (2021). Dynamics of renewable energy consumption on environmental sustainability: Empirical evidence from the GCC countries. Environmental Science and Pollution Research, 28(14), 17369–17380. https://doi.org/10.1007/s11356-020-11776-2
17. Destek, M. A., & Sinha, A. (2020). Renewable, non-renewable energy consumption, economic growth, trade openness and ecological footprint: Evidence from OECD countries. Journal of Cleaner Production, 242, 118537.
18. Sbia, R., Shahbaz, M., & Hamdi, H. (2014). A contribution of foreign direct investment, clean energy, trade openness, carbon emissions and economic growth to energy demand in the UAE. Economic Modelling, 36, 191–197.
19. Ali, W., Yusop, Z., & Hook Law, S. (2022). Foreign direct investment and renewable energy consumption in Somalia: Empirical evidence from ARDL approach. Renewable Energy, 189, 904–913.
20. Shahbaz, M., Loganathan, N., Zeshan, M., & Zaman, K. (2015). Does renewable energy consumption add to economic growth? An application of auto-regressive distributed lag model in Pakistan. Renewable and Sustainable Energy Reviews, 44, 576–585.
21. Pesaran, M. H., & Shin, Y. (1999). An autoregressive distributed lag modeling approach to cointegration analysis. In S. Strom (Ed.), Econometrics and Economic Theory in the 20th Century: The Ragnar Frisch Centennial Symposium (pp. 371–413). Cambridge University Press.