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Energy security of Uzbekistan in the context of fuel and energy transformation: challenges, strategies and prospects

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Abstract: The article examines the state and prospects of Uzbekistan's energy security in the context of significant changes in the fuel and energy sector. Key issues examined were the heavy reliance on fossil fuels, physical and moral deterioration of infrastructure, growing domestic needs, and the interdependence of hydropower in Central Asia. The focus is on the implementation of the national green economy strategy, which involves the diversification of the energy balance through the large-scale introduction of renewable energy sources, the modernization of energy storage systems, networks and the development of regional cooperation.

INTRODUCTION

Context and relevance of the issue. Energy security is understood as a reliable, sustainable and affordable energy supply to the economy and population and is the cornerstone of state sovereignty and sustainable development of Uzbekistan. The country of more than 38 million people and a growing economy traditionally depends on rich gas reserves. However, the model has faced a number of key challenges in recent years. One of the key factors is material and moral damage to infrastructure: more than half of the distribution network facilities have been operating for more than 30 years, which leads to a loss of about 13% of technical electricity and frequent interruptions in supply [1].

The infrastructure crisis has been accompanied by a growing need to diversify the historically fossil fuel-based energy portfolio. The response to these systemic risks was a firm strategic approach embodied in the "National Green Economy Transition Strategy 2019-2030." Uzbekistan has set ambitious goals: to increase the share of renewable energy sources in the energy balance to 30% by 2030 and to reduce greenhouse gas emissions by 35%[2]. The implementation of this strategy has led to the prosperity of the renewable energy sector. So, in 2024, in some periods, the share of solar and wind generation reached 18%, and by the end of the year it is planned to bring this figure to 18% of the total generation [3]. Masdar (UAE) and ACWA Power The world's largest developers, such as (Saudi Arabia), are implementing solar and wind farm projects in the country in gigawatts [2,3].

Energy security is understood as a reliable, sustainable and affordable energy supply to the economy and population and is the cornerstone of state sovereignty and sustainable development of Uzbekistan. The historical dependence on natural gas was the basis for the generation of electricity and heat, which periodically led to a shortage of electricity and power outages in the context of the gradual depletion of the most accessible fields, the moral and physical deterioration of infrastructure during the Soviet era and the annual increase in energy consumption.

Uzbekistan's energy transformation has gone beyond the simple construction of solar and wind farms, whose total capacity will reach 4.8 GW by 2024. A key challenge, however, is integrating variable generation from renewable sources into vulnerable and often congested power systems. Outdated power grids managed by JSC National Power Grid of Uzbekistan face heavy losses and insufficient flexibility to balance peak production and consumption loads. Therefore, the country's energy security today depends not only on the volume of generating capacities, but also on the ability of energy systems to stably and effectively integrate new environmentally friendly energy sources.

Uzbekistan is actively developing a battery-based energy storage system (BESS), which is becoming a key solution to solve current energy problems. The BESS market is going through an important stage: after a successful pilot project in the Ferghana region (with a capacity of 150 MW/300 MW), the country is moving to the implementation of the state program. An example is the signing in November 2025 of an agreement with Masdar (UAE) on the construction of the Zarafshan BESS autonomous complex, which will have a capacity of 300 MW/600 MW. These projects are not considered as additional measures, but as backbone initiatives aimed at ensuring frequency control, smoothing peak loads and creating power reserves.

LITERATURE ANALYSIS

The issues of energy security and the transition to sustainable energy in Uzbekistan and Central Asia are actively studied by both national and international researchers and institutions. Existing research can be divided into several key areas to create a theoretical and contextual framework for this analysis.

The first group includes basic research and analytical reports on energy security and economic development of Uzbekistan. Scientists such as M.A. Iskandarova and D.N. Karimova study in detail the dependence of the country's economy on the hydrocarbon sector. Their work analyzes the risks associated with the depletion of natural resources and the deterioration of infrastructure [6, 7]. These studies provide a basic understanding of the structural challenges facing the country. The analytical comments of the leading analytical agencies of Uzbekistan contain up-to-date statistics and assessments of the current state of the energy sector, which makes it possible to track the dynamics of changes. [1, 3].

The second group of literature focuses on the context of Central Asia. Including a collective monograph edited by A. Saidov. A number of studies focus on a comprehensive analysis of hydropower links between the countries of the region [8]. During these studies, the historical interdependence of Uzbekistan, Tajikistan and Kyrgyzstan in the use of transboundary water resources for irrigation and hydropower was emphasized. International reports such as the United Nations Development Programme (UNDP) also emphasize the need for cross-border cooperation as a key factor for long-term stability and energy security throughout the region [9].

The third group of studies was devoted to the study of a green transition strategy and the development of renewable energy sources. This was based on official government documents such as the National Green Economy Transition Strategy 2019-2030. In their article, researchers Abdullaev I.R. and Khodzhaev L.S. conducted a detailed analysis of the implementation of these strategies and their economic aspects. They studied the investment attractiveness, tariff policy and the socio-economic impact of the introduction of renewable energy sources [10, 11]. These studies have important implications for understanding the mechanisms and potential for diversification of the energy balance.

In the fourth part, the literature group is devoted to technical problems of renewable energy integration, in particular the role of energy storage systems (BESS). This direction is relatively new for the region. An innovative analytical report, for example, a study by the ANARIYEV agency, was the first to systematically prove the critical need for the introduction of BESS to stabilize the energy system of Uzbekistan with an increase in the share of sun and wind [4]. This work fills important gaps by linking generation development issues with energy supply reliability and sustainability issues.

The fifth group includes publications and reports from international financial institutions such as the World Bank, the European Bank for Reconstruction and Development and the Asian Development Bank. These documents contain not only financial analysis, but also recommendations on institutional reforms, improved regulation and implementation of international best practices in the field of network modernization and energy transition management [5]. They serve as an important source for assessing the role of international cooperation in strengthening the energy security of Uzbekistan.

The research gap identified: in modern research covering the economy, regional relations and the development of renewable energy sources (RES), there is no comprehensive approach that would combine all these aspects into a single analytical framework. In particular, the interaction of three key components has not been sufficiently studied: 1. RES implementation rate. 2. Flexible energy storage (BESS) deployment rates. 3. Progress in upgrading network infrastructure.

This study aims to address this gap by analyzing Uzbekistan's energy security in terms of synergy or imbalance between these three strategic areas.

Formulation of scientific tasks. However, the rapid expansion of variable-source power generation, such as solar and wind power, poses new threats to the stability of the energy system. Without effective methods of balancing and storing excess energy, the integration of renewable sources will not only not increase, but can significantly reduce the

level of energy security, which will lead to fluctuations in frequency and voltage in the power grids. Thus, the key scientific and practical task is not only the development of renewable energy sources, but also their controlled introduction into existing energy systems. Currently, Uzbekistan's energy security is largely determined by the country's ability to create a modern, adaptive and reliable energy infrastructure capable of effectively accumulating, transporting and distributing green energy without compromising the stability of supplies.

Purpose and objectives of the study

The purpose of the study - as part of the implementation of the Green Transition strategy, a comprehensive analysis of the state of energy security of Uzbekistan was carried out. The study identified key factors affecting the long-term sustainability of the country's energy sector. To achieve the set goals, the following tasks were identified:

1. assessment of the current state of the fuel and energy complex of Uzbekistan and identification of the main challenges to ensure the country's energy security.
2. analysis of strategic directions of public policy, as well as tools and intermediate results of diversification of energy balance and development of renewable energy sources.
3. Research on the importance of regional hydropower cooperation and international partnerships for strengthening national energy security.
4. Assessment of technological and infrastructural problems associated with the integration of intermittent electricity production based on renewable sources, as well as an analysis of the role of energy storage systems (BESS) in their solution.
5. Development of recommendations on priority measures to improve the energy security of Uzbekistan.

MAIN PART

1. Current state and internal challenges of energy security

The energy system of Uzbekistan is at the stage of active growth and structural changes. For the nine months of 2025, electricity production increased by 3.8% compared to the same period in 2024, reaching 62.54 billion kWh. One of the key trends is a significant increase in small business generation, which has grown by more than 2.5 times, which indicates the development of distributed energy. Thanks to large-scale investments, the installed capacity of the power system has increased to 25 GW, which in five years represents an increase of 50%.

Despite the successes achieved, serious structural problems remain. First, although the share of gas is gradually decreasing, the power system is still heavily dependent on it. Secondly, physical deterioration of infrastructure leads to high losses in networks. While the loss rate has fallen from 16% to 11% in recent years, it remains significant according to various estimates. Thirdly, the rapid growth in the share of variable renewable energy sources does not provide sufficient balance and capacity expansion, which poses new risks to the stability of the energy system.

2. Diversification strategy: policy and implementation of renewable energy projects

The implementation of the "National Strategy for the Transition to a Green Economy" is a systematic approach to solving pressing problems. The focus is on the energy sector. By 2024, it is planned to achieve the installed capacity of renewable energy sources (RES) about 20% of the total fleet, including hydroelectric power plants (HPPs) - 10%, solar energy - 9%, and wind energy - 1%. The strategic goal is to increase the share of renewable energy sources in the energy balance by 2030 to 30%, while the total capacity should reach 20-25 GW.

To achieve these ambitious goals, the public-private partnership model is actively used, which attracts large investors and developers from around the world. Over the past five years, foreign investment in the energy sector has amounted to more than \$25 billion. In 2025, new projects worth 9.46 billion euros were announced, including 16 renewable energy facilities with a total capacity of 3.5 GW. Key participants are the UAE (Masdar), Saudi Arabia (ACWA Power) and France (TotalEnergies, Enel). Tatarstan companies are also implementing projects to create gigawatts of solar and wind power plants.

3. Regional and international energy security contexts

Uzbekistan's energy security is inextricably linked to regional cooperation in Central Asia. The water balance of the Syr Darya river basin, where the strategic Toktogul reservoir of Kyrgyzstan is located, is crucial. As a downstream country, Uzbekistan relies on a system of droplets necessary for agriculture. In return, it provides Kyrgyzstan with electricity and fuel in winter. This interdependence requires constant negotiation and signing of annual protocols, as was done at the trilateral conference in Cholpon Ata in 2025. Building capacity for such dialogue is key to regional stability.

At the broader international level, Uzbekistan is actively integrating into the new structure of cooperation. This includes participation in the Shanghai Cooperation Organization (SCO) 2030 energy cooperation roadmap, as well as

a project to create a green energy corridor for exporting electricity to Europe through Azerbaijan and Kazakhstan. This multi-level partnership facilitates the flow of technology, funding and strengthens the diplomatic position of the state.

A strong international partnership is a key element of the ongoing transformation. Uzbekistan not only attracts foreign direct investment for the production and creation of reserves, but also closely cooperates with the World Bank, the European Bank for Reconstruction and Development, the Asian Development Bank and other institutions in developing strategic policies, regulatory frameworks and strengthening institutional capacity for a green transition [2, 5]. Such cooperation helps reduce investment risks and ensures the transfer of modern knowledge and technology.

Currently, the energy security of Uzbekistan is undergoing a stage of significant changes caused by the need to overcome infrastructure problems and implement climate goals. The success of these transformations depends on three key factors: 1) widespread adoption of renewable energy technologies, 2) creation of flexible capabilities, including energy storage systems (BESS), to maintain balance in the energy system, 3) deep modernization and digitalization of network infrastructure. The purpose of this study is to analyze this complex process and assess the interaction between technological initiatives, public policy and international assistance in the formation of a new structure of the country's energy security.

4. Technology and Infrastructure Challenges: The Role of BESS and Network Modernization

The increase in the share of solar and wind energy has led to new challenges for the stability of energy systems. Uneven production from renewable sources makes load balancing difficult, especially in the evening, when electricity demand peaks. Battery-based energy storage systems (BESS) help solve this problem. Uzbekistan understands the importance of this technology: by 2025, it is planned to install a BESS with a capacity of 1.8 GW. In addition, the new initiative will introduce 10 utility energy storage systems with a total capacity of 1,245 MW. These systems will accumulate surplus solar energy generated during the day and supply it to the grid during high demand hours, which will improve frequency control and increase the reliability of power supply.

In parallel, large-scale modernization is being carried out in the power grids. It is planned to build thousands of kilometers of new high-voltage power lines and digitalize networks to optimize traffic management. An innovative step was the transfer of regional distribution networks, such as the network in Samarkand, under the management of foreign companies to increase efficiency and reduce losses.

Table 1. Main projects and goals of diversification of Uzbekistan's energy balance (to 2024-2025)

Direction	Current indicator (2024)	Target/Project 2025-2030	Value for energy safety
Share of renewable energy sources in the energy balance	10% (excluding large HPPs)	30% by 2030	Reduction of gas dependence, use of local resource
Solar SES power	3.3 GW	Increase to 10 GW by 2030; launch of new 3.5 GW projects in 2025	Generation Diversification, Peak Day Load Coverage
Power of wind SPP	1.5 GW	Increase to 12.5 GW by 2030	Use of wind potential, generation in different periods of the day
Storage Capacity (BESS)	Initial Implementation Phase	Commissioning of 1.8 GW in 2025; 1,245 MW of new systems announced	Network stabilization, RES integration, reliability assurance
GHG emissions reduction	-20% (rel. 2010)	-35% by 2030	Meeting climate commitments, improving the environment

RESULTS AND DISCUSSION

The study demonstrates that Uzbekistan is implementing large-scale and dynamic reforms of its energy system that affect all aspects of energy security.

1. energy supply and diversification: the active development of renewable energy sources radically changes the structure of the energy balance, reducing dependence on fossil fuels and increasing the importance of domestic resources that cannot be depleted. This strengthens the long-term sustainability of supplies and minimizes currency risks associated with the import of equipment from thermal power plants. The authorities declared the possibility of providing all home consumers with green energy by 2026, which indicates the ambitiousness of the current course.

2. Reliability and stability of power systems: the introduction of energy storage systems (BESS) and network modernization are aimed at solving key problems of the new energy paradigm. BESS not only serves as an auxiliary technology, but also becomes an integral part of the system, providing balance and flexibility. However, the success of these measures depends on the capacity of renewable energy, synchronism of drives and related network facilities. Any deviation from these factors creates new risks to the reliability of power systems.

3. Regional and international interdependence: Uzbekistan has moved from isolationist policies to active participation in regional and global initiatives. The tripartite water balance agreement has become an effective tool for joint water management and risk mitigation. The involvement of the world's leading companies and financial institutions not only provides the necessary investments, but also contributes to the introduction of advanced technologies and management practices.

The key challenge remains the ability of the national institutional system, legal framework and human resources to adapt to managing the complex and distributed energy systems of the future. In addition, social justice issues remain during the transition period related to plans to develop clean energy and create new green jobs for low-income families.

CONCLUSIONS

Uzbekistan has clearly indicated its determination to make energy transition a key factor in ensuring long-term energy security. A diversification strategy based on the use of renewable energy sources, the introduction of energy storage systems, the modernization of infrastructure and the intensification of international cooperation is a complex, but generally relevant task.

To minimize risks and strengthen the results achieved, it is necessary to focus on the following aspects:

1. Institutional and regulatory capacity development: the development and implementation of detailed technical regulations, standards and market mechanisms should be accelerated to recognize the value of energy storage systems and distributed generation services. Consideration should be given to introducing mandatory requirements for energy storage systems at large renewable energy facilities.

2. Synchronous investments in power generation, networks and drives: the project should be planned and implemented as part of a single comprehensive program, in which each new gigawatt of renewable energy will be accompanied by an approved plan to strengthen the network infrastructure and implement the corresponding capacities of energy storage systems.

3. Strengthening regional integration: Moving from temporary agreements to sustainable, legally enforceable multilateral electricity exchange mechanisms. Sharing energy capacity, including hydroelectric and energy storage batteries, and creating a balanced regional market.

4. Technology localization and workforce development: It is important to encourage joint ventures to produce key components for renewable energy and energy storage systems. It is necessary to expand the training and retraining programs for engineers, technicians and managers to work in the conditions of the new power system.

5. Ensuring social harmony during the transition period: programs to support households in installing solar panels should be expanded, the benefits of the transition period for the population should be clearly outlined, and professional retraining programs should be developed in coal mining regions.

The implementation of these measures will allow Uzbekistan not only to ensure its energy security, but also to strengthen its position in the region as a leader in the field of sustainable energy.

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