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Energy efficiency as a driver of resource-based production transformation: the case of Uzbekistan

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Abstract. This article examines the key role of energy efficiency policy in transforming the resource potential of industrial production and housing and communal services in Uzbekistan. Analysis of statistical data, legislative acts and the results of social surveys for the period from 2017 to 2025 revealed a direct relationship between the introduction of energy-saving technologies, infrastructure modernization and a decrease in the energy intensity of the gross domestic product. The study showed that a set of measures, including price liberalization, large-scale implementation of LED lighting, thermal modernization of buildings and the development of renewable energy sources, not only led to significant savings in resources, but also laid the foundation for sustainable low-carbon economic development. In conclusion, it is concluded that it is necessary to further integrate digital technologies and deepen international cooperation to consolidate the results achieved.

INTRODUCTION

The current stage of global economic development is characterized by growing pressure on the environment and the depletion of traditional energy resources, which makes the search for new paradigms of industrial growth extremely urgent. In the context of the transition to sustainable development models and the implementation of the Paris Agreement climate commitments, issues of resource-based production transformation are particularly important for emerging markets and energy-intensive industrial complexes [3, c.15]. The Republic of Uzbekistan, which possesses significant but dwindling hydrocarbon reserves, with a historically resource-intensive economic structure and outdated production infrastructure, is faced with a complex of interrelated problems.

Key factors include: continued growth in domestic energy demand driven by demographic trends and industrialization; significantly higher than the global average energy intensity of gross domestic product (GDP); physical and technical deterioration of the fuel and energy complex (FEC) and industrial fixed assets; and the need to meet international environmental obligations [1, c.5; 2, c.8]. In this context, the strategic direction of improving energy efficiency has transformed from a narrow-technical problem into a system driver of comprehensive modernization, which can create a synergistic effect at the intersection of economic, environmental and technological development.

In 2017, Uzbekistan launched a comprehensive program of deep structural reforms in the energy and industrial sectors, laying the institutional foundation for a transition from an extensive model of resource consumption to an intensive one. The adoption of new editions of the laws “On the Use of Renewable Energy Sources,” “On the Electric Power Industry,” and “On Public–Private Partnership,” along with the implementation of a roadmap for energy market liberalization, created the necessary prerequisites for attracting investment and introducing best available technologies [1, pp. 12–14]. However, despite significant achievements at the initial stage of transformation, there is still a lack of comprehensive scientific research that systematically evaluates the role and effectiveness of energy efficiency policy in stimulating resource transformation across the entire production sector, rather than viewing it solely as a cost-reduction instrument.

The relevance of this study is due to the need for a comprehensive assessment of the experience gained by Uzbekistan in the field of reforms aimed at energy saving and resource saving. The goal is to identify causal

relationships between the measures taken and their macroeconomic, sectoral and social consequences, as well as to develop evidence-based recommendations for the further stage of transformation.

Academic knowledge of this issue is reflected in the analysis of global energy efficiency trends by such scientists as A.M. Iskenderov and K.O. Irisalieva, as well as in research analytical reports of international organizations (GIZ, ADB, World Bank) on the reform process in Uzbekistan. However, studies integrating the analysis of transformations in the technical, economic and behavioral spheres into a single system are currently insufficient.

The purpose of the study is a comprehensive analysis of energy efficiency policies as a key factor in the transformation of Uzbekistan's production resources, as well as an assessment of its effectiveness based on specific macroeconomic and sectoral data.

In order to achieve these objectives, the study will:

Analysis of institutional and macroeconomic prerequisites for the transition to a resource-saving model of the economy.

Assessment of the results of the implementation of the state energy efficiency policy and its impact on reducing the energy intensity of the gross domestic product (GDP).

Exploring technological and behavioral change at the industry and household level.

Identification of persistent problems and unrealized potential.

Develop evidence-based recommendations to further deepen resource transformation.

The theoretical and methodological basis of this study is a systematic approach, as well as methods of statistical, comparative, sociological and legal analysis.

The scientific novelty of the work lies in the application of an interdisciplinary approach, which considers energy efficiency as a systemic phenomenon that has a transformative effect on the entire production and consumer structure of Uzbekistan, as well as in the generalization of the latest empirical data, many of which are first introduced into scientific circulation.

The practical significance of the results of the study is that its conclusions and recommendations can be used by government agencies in the development and adjustment of plans for the development of industries, industrial enterprises in planning modernization, as well as the scientific community for further research in this area.

Literature analysis

Energy efficiency issues are widely discussed by scientists both in China and abroad. In the work of A. M. Iskenderov and K. O. Irisalieva [4, p. 165], an analysis of the energy efficiency of industrial enterprises around the world was carried out. The authors emphasize that improving energy efficiency is a strategic direction for reducing energy consumption in the economy. They note that global decarbonization and decentralization of energy are part of the fourth energy revolution.

International organizations such as the World Bank, the Asian Development Bank (ADB) and the German Society for International Cooperation (GIZ), in their reports and analytical notes, examine in detail the progress of reforms in Uzbekistan. The materials of GIZ [2] state that outdated and inefficient technologies in the production sector of Uzbekistan lead to low energy efficiency and low competitiveness of industry. ADB, in turn, focuses on the role of public-private partnerships (PPPs) and the need to create a favorable investment climate to mobilize private capital in the energy sector [3].

International organizations such as the World Bank, the Asian Development Bank (ADB) and the German Society for International Cooperation (GIZ) study the progress of reforms in Uzbekistan in detail in their reports and analytical notes. GIZ materials [2] indicate that outdated and inefficient technologies in the manufacturing industry of Uzbekistan lead to low energy efficiency and weak competitiveness of the industry. ADB, in turn, emphasizes the role of public-private partnerships (PPPs) and the need to create a favorable investment climate to attract private capital to the energy sector [3].

The key role of energy efficiency in the modernization of the economy of Uzbekistan is widely recognized in scientific literature and analytical reports. However, a comprehensive analysis of the impact of energy efficiency on the transformation of production resources has not yet been carried out, taking into account the latest empirical data, which is the scientific novelty of this study.

METHODOLOGY AND DATA

The methodological basis of the study is a systematic approach that allows us to consider energy efficiency as a multifaceted phenomenon affecting economic, technological and social development. A set of methods was used in the work, including both general scientific and special:

Statistical analysis is used to identify the dynamics of macroeconomic indicators, such as GDP growth, a decrease in energy intensity, an increase in electricity generation and changes in the structure of energy consumption. The data are obtained from official reports of the Center for Economic Research and Reforms (CEIR) of Uzbekistan [1] and international organizations [5].

The comparative analysis is aimed at comparing the state and policy of the energy sector of Uzbekistan with international best practices, in particular, with the practice of Japan.

The sociological approach is used to analyze the results of sample household surveys conducted by the Center for Economic Research and Reform (CEIR) [1], covering 3,516 households across the country, as well as data on 3.5 million natural gas consumers and 8 million electricity consumers. This helps assess the behavioral aspects of the reforms.

The analysis of legislation and regulations includes the study of the legal framework of reforms, including 8 laws adopted between 2017 and 2024, as well as more than 90 decrees of the President and decisions of the Cabinet of Ministers [1].

The study period covers 2017-2025, which allows us to trace the causal relationships between the measures taken and their results.

Goals and objectives of the study:

This study is aimed at relying on specific data to convincingly prove that energy efficiency is a key factor in resource transformation in the areas of production and consumption of Uzbekistan.

Research objectives:

Analyze key directions of state policy in the field of energy efficiency and their regulatory support.

To quantify the achieved macroeconomic and sectoral results of reforms.

To investigate behavioural changes at the household level as a reaction to new market incentives.

Identify untapped potential and formulate concrete proposals to further improve energy efficiency.

MAIN PART

Institutional and macroeconomic transformation background. The awareness of the Uzbek authorities of the risks associated with the depletion of resources and the high energy intensity of the economy has become a starting point for transformation. As noted in the GIZ report [2], Uzbekistan remains one of the countries with the highest energy consumption and carbon emissions in the world. To address these challenges, Uzbekistan has undertaken a number of deep institutional reforms. 8 laws and more than 90 by-laws were adopted, laying the foundation for the transition to market mechanisms. This includes the restructuring of state-owned energy concerns, the separation of the functions of energy production, transmission and distribution (decentralization), as well as the adoption of new laws on renewable energy sources and public-private partnerships (PPPs) [1, 3].

1. the macroeconomic effects of these measures manifested themselves in the medium term. From 2017 to 2024, Uzbekistan's GDP grew by 55%, and the energy intensity of the economy decreased by 7.4%[1]. This means that the economy has begun to produce more value with less energy consumption. A unit of added value of one million soums accounts for 56.8 kilowatt-hours [1]. consumed energy. At the same time, 11,000 megawatts of generating capacity were added, which is three times more than in the previous 25 years.

2. Technological modernization and changing consumption patterns

A key element of the reform was tariff liberalization, introduced in May 2024, which combined the social norm of consumption with economic incentives to save. The results were significant: in the period from May to December 2024, electricity consumption decreased by 10.6% compared to the same period in 2023, which is equivalent to savings of 1.3 billion kWh [1]. Regions with a previously high level of energy consumption have most noticeably reduced their consumption.

At the household level, reforms have facilitated a massive shift to energy-saving practices. Studies show that more than 90% of respondents have taken at least one energy-saving measure [1]. The most popular was the replacement of lighting with LED (87% of households). In addition, a significant part of the population insulated windows and doors (44%) and purchased energy-efficient household appliances (31%). These changes in behavior indicate the formation of a new culture of resource consumption.

3. Development of renewable energy sources and distributed generation.

Along with energy saving measures, renewable energy sources are actively developing. By the end of 2024, fourteen solar and three wind farms with a total installed capacity of 4,100 megawatts were commissioned in ten regions of the country. Green electricity generation for this year amounted to 4.9 billion kilowatt-hours.

International partners such as the Asian Development Bank and the European Bank for Reconstruction and Development have played a significant role in providing advisory services, loan guarantees and direct financing for public-private partnership projects such as the Sherabad solar power plant [3].

At the micro level, there is a boom in distributed generation. Already 64,000 households have installed solar panels with a total capacity of 223.4 MW, with an annual production of about 313 million kWh [1]. The potential demand for solar panels is estimated at 1.9 million households, which opens up prospects for the development of the domestic market with a volume of over 2.3 billion US dollars [1].

At the micro level, distributed energy generation is showing rapid development. Solar panels have already been installed in 64,000 households, total installed capacity has reached 223.4 megawatts, and annual power generation is about 313 million kilowatt hours [1]. The potential demand for solar panels is estimated at 1.9 million households, opening up prospects for a domestic market of over US $2.3 billion.

4. International cooperation and risk management.

The experience gained by Japan in the field of knowledge and technology exchange in 2025 taught Uzbekistan valuable lessons [5]. Japan's approach to disaster-resistant energy systems, including the use of "digital twins" to visualize power grids, the development of energy storage systems (including pumped storage power plants) and the introduction of advanced measuring infrastructure (more than 78.5 million smart meters), offers Uzbekistan ready-made solutions for risk management when integrating unstable renewable energy sources.

Results and discussion

The study reveals the complex results of resource transformation based on the principles of energy efficiency, and discusses their systemic significance for the economy of Uzbekistan.

This study is aimed at revealing the complex results of resource transformation based on energy efficiency principles and studying their systemic significance for the economy of Uzbekistan.

1. Macroeconomic results and structural changes

Statistical data analysis [1, c. 18-20] demonstrates steady positive dynamics of key macroeconomic indicators:

Analysis of statistical data [1, c.18-20] shows that key macroeconomic indicators demonstrate stable positive growth dynamics.

Table 1. Resource Transformation Key Macroeconomic Indicators

Indicator	2017 year	2024 year	change
Energy intensity of GDP (kt.o./million $)	0.48	0.44	-7.4%
Share of renewable energy sources in electricity generation	0.8%	12.3%	+11.5 p.p.
Industrial productivity (index)	100	122	+22%

Particular attention is drawn to the structural transformation in the energy sector. In 2017, the share of renewable energy sources was insignificant, but by 2024, every eighth kilowatt-hour of electricity in the country was produced from renewable sources. This indicates the beginning of the transition from monopoly dependence on natural gas to a diversified energy system.

2. industry efficiency and technological modernization

At the sectoral level, the most significant results were achieved in the industrial sector:

Cement industry: A 35-40% reduction in specific energy consumption confirms the effectiveness of the transition to a dry production method.

Metallurgical complex: Saving 25% of electricity at Almalyk MMC is an impressive result. However, the controversial issue remains the high capital intensity of such projects, which limits their replication at medium and small enterprises in the industry.

Textile industry: The reduction in energy consumption by 15-18% was achieved mainly due to the introduction of variable frequency drives. According to GIZ experts [2, c.33], the potential for additional savings (another 10-12%) is associated with the modernization of ventilation and air conditioning systems.

A decrease in specific energy consumption by 35-40% confirmed the efficiency of the transition to a dry production method.

Metallurgical complex: Saving 25% of electricity at the Almalyk mining and metallurgical plant is an impressive result. However, the high capital intensity of such projects remains a controversial issue, which limits their distribution in medium and small enterprises in the industry.

3. Behavioral changes and social aspects

Prevalence of energy-saving measures among households.

LED lighting: 87%
Window/door insulation: 44%
Energy efficient machinery: 31%
Solar panels: 2.1%

The discussion of these results reveals an interesting pattern: measures with a short payback period (for example, LED lighting) are most popular, while capital-intensive projects (such as the modernization of heating systems or the installation of solar panels) have a lower level of implementation. This indicates the need to develop financial mechanisms (for example, installments, concessional loans) to stimulate deep energy-efficient modernization.

4. Comparative analysis of the effectiveness of public policy measures. Based on the analysis of the implementation of state programs, the most effective measures can be distinguished:

Table 2. Effectiveness of Public Policy Measures

Measure	Effect	Payback period
Tariff liberalization	10.6% reduction in consumption	Instant
RES support	Generation growth by 4.9 billion kWh	5-7 years
Technological modernization	Energy savings 7.4%	3-5 years

As the discussions of ADB experts [3, p. 41] showed, the measures combining economic incentives (tariff reform) and institutional support (public-private partnership in the field of renewable energy) showed the greatest effectiveness.

5. untapped potential and bottlenecks

Despite the successes achieved, the study revealed significant reserves:

Energy efficiency potential in housing and utilities: A discussion by Asian Development Bank experts showed [3, p. 41] that measures combining economic incentives (tariff reforms) and institutional support (public-private partnership in the field of renewable energy) demonstrate the greatest efficiency.

Digitalization of energy systems: As shown by a study of Japanese experience [5, p. 57], the introduction of intelligent accounting and control systems can further reduce the peak load by 15-20%.

Industrial efficiency: According to GIZ estimates [2, p. 47], the energy saving potential in the food and light industries has been realized only by 40-45%, which is associated with a shortage of qualified personnel and limited long-term financial channels.

6. Discussion issues and risks. Economic feasibility: The high capital intensity of some renewable energy projects (payback period of 5-7 years) requires finding the optimal balance between the speed of transition and the financial burden on the economy.

Social acceptability: Energy prices, which will need to be further increased for a return on investment in renewable sources, may face social resistance.

Technological dependence: The active introduction of foreign technologies carries the risk of dependence on the import of equipment and know-how.

Thus, the results of the study confirmed the effectiveness of the established course towards transforming resources by improving energy efficiency, but also revealed the need for a more balanced approach to risk management and the realization of untapped potential.

Conclusions and suggestions

Based on the study, the following conclusions and proposals are formulated:

Conclusions:

1. energy efficiency has become a key factor in the transformation of the economy of Uzbekistan, ensuring the growth of added value while reducing energy consumption per unit of production.

2.The success of the reforms is due to an integrated approach combining drastic measures, such as tariff liberalization, with softer ones, for example, stimulating technological innovation and changing consumer behavior.

3. International cooperation with partners such as the Asian Development Bank, the World Bank and the German Society for International Cooperation (GIZ), as well as the use of foreign experience, in particular Japanese, played a decisive role in the successful planning and implementation of the transformation.

Suggestions:

1. Develop and implement a national program of deep modernization of heating systems for residential and public buildings, attracting public-private partnership mechanisms and concessional lending.

1. accelerate the digitalization of the energy system through the large-scale introduction of smart meters, the creation of digital twins of distribution networks and the development of virtual power plant (VPP) services for the integration of distributed energy resources.

2. Strengthen educational and consulting activities aimed at popularizing energy-saving behavior and introducing energy-saving technologies in small and medium-sized enterprises.

3. Monetize the environmental benefits of improving energy efficiency by further developing Uzbekistan's carbon market and integrating it with international climate funds to stimulate green investment.

REFERENCES

1. Uzbekistan’s Energy Transformation: A Phased Transition to Market Mechanisms. (2024). Center for Economic Research and Reform (CERR). - Tashkent, 2024. - 45 s.
2. Supporting green industrialisation in Uzbekistan. (2023). Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. - Bonn, 2023. - 28 s.
3. Driving Uzbekistan's Renewable Energy Growth Through PPPs and Policy Reform. (2025). Asian Development Bank. - Manila, 2025. - 52 s.
4. Iskenderov A.M., Irisalieva K. O. Analysis of energy efficiency of industrial enterprises at the world level//Interpretation and Researches. - Tashkent: 2025. – №1(47). - S. 164-167.
5. Building a Resilient, Sustainable Energy Future: What Uzbekistan Can Learn from Japan. (2025). The World Bank, GFDRR. - Washington, 2025. - 67 s.
6. Xusainov, R. (2025). Renewable energy sources as the basis of a green economy in Uzbekistan. science, 4(s1-2), 94-102.
7. Gulchekhra Allaeva, Gulchekhra Yusupkhodjaeva, Kamola Mukhitdinova, Methodology for calculating sustainable development of fec enterprises based on consolidated integral indices. AIP Conf. Proc. 3331, 030006 (2025) https://doi.org/10.1063/5.0308133
8. Gulchekhra Yusupkhodjaeva, Gulchekhra Allaeva, Kamola Mukhitdinova, Sustainable development of transport enterprises in the context of the formation of the digital economy. AIP Conf. Proc. 3331, 030087 (2025) https://doi.org/10.1063/5.0306872
9. Kamala Mukhitdinova, Gulchekhra Yusupkhodjaeva, Gulchekhra Allaeva, Econometric modeling of investment potential of industrial enterprisess. AIP Conf. Proc. 3331, 050026 (2025) https://doi.org/10.1063/5.0308123
10. Gulchekhra Allaeva, Main directions of sustainable development of fuel and energy enterprises. AIP Conf. Proc. 3152, 050012 (2024) https://doi.org/10.1063/5.0220851
11. Gulchekhra Allaeva, The role of energy security in forming the foundations for sustainable development of fuel and energy complex enterprises. In E3S Web of Conferences 461, 01061 (2023), https://doi.org/10.1051/e3sconf/202346101061
12. Gulchekhra Allaeva, Sustainable development methodology of fuel-energy complex of the republic of Uzbekistan. In E3S Web of Conferences 289, 07033 (2021) https://doi.org/10.1051/e3sconf/202128907033
13. Gulchekhra Allaeva, Fiscal instruments of taxation improvement as a factor of sustainable development of enterprises of the fuel and energy sector. In E3S Web of Conferences 216, 01173 (2020) https://doi.org/10.1051/e3sconf/202021601173
14. Gulchekhra Allaeva, Priority directions of development “Uzbekneftegas” jsc in the conditions of globalization of the world economy. In E3S Web of Conferences 139, 01008 (2019) https://doi.org/10.1051/e3sconf/201913901008
15. Saodat Ibragimova, Khilola Bakhodirova, Formation of investment activities of energy enterprises. E3S Web of Conferences 461, 01074 (2023) https://doi.org/10.1051/e3sconf/202346101074
16. Ravshan Xusainov, Otabek Begmullaev, Problems of ensuring the electricity supply system in Uzbekistan. In AIP Conference Proceedings. 3331, 030002 (2025) https://doi.org/10.1063/5.0305927
17. Ravshan Xusainov, Barno Tillayeva, Nigina Sayfutdinova, Development of ecology and energy in Uzbekistan. AIP Conf. Proc. 3331, 030010 (2025) https://doi.org/10.1063/5.0306384
18. Gulchekhra Yusupkhodjaeva, Development of a unified digital transport and logistics intelligent platform based on the National Operator. E3S Web of Conferences 461, 01055 (2023) https://doi.org/10.1051/e3sconf/202346101055
19. Kamola Mukhitdinova, Gulmira Tarakhtieva, Ensuring sustainable future: The interconnectedness of food safety and environmental health. E3S Web of Conferences 497, 03037 (2024) https://doi.org/10.1051/e3sconf/202449703037

20. Hashimova, S., Yakubova, D., Tursunova, N. (2024). Possibilities of Expanding the Mineral Resource as a Base of Ferrous Metallurgy. In Lecture Notes in Networks and Systems, vol 733. Springer, Cham. https://doi.org/10.1007/978-3-031-37978-9_70
21. Sarvinoz Salomova, Matlyuba Saidkarimova, Latofat Karieva, Kamola Ibragimova, Gulnora Saidova, Ravshan Khikmatov, Improving the efficiency of energy enterprises AIP Conf. Proc. 3331, 040076 (2025) https://doi.org/10.1063/5.0305987
22. Otabek Begmullaev, Saidaxon Nabieva, Shakhnoza Mirsaidova, Classification of energy efficiency policies and their implementation Available to Purchase. In AIP Conference Proceedings. 3331, 030053 (2025) https://doi.org/10.1063/5.0305929
23. Otabek, A., Otabek, B. Alternative energy and its place in ensuring the energy balance of the Republic of Uzbekistan. In AIP Conference Proceedings, 2023, 2552, 050030 https://doi.org/10.1063/5.0117633
24. Akhmedov, O., Begmullaev, O. The ways ensuring energy balance in Uzbekistan. In E3S Web of Conferences 216, 01137 (2020), https://doi.org/10.1051/e3sconf/202021601137
25. Saidakhon Nabieva, Shakhnoza Atakhanova, Modern methods of investment activity in the development of industrial enterprises. AIP Conf. Proc. 3331, 050010 (2025) https://doi.org/10.1063/5.0308119
26. Sarvinoz Salomova, Increasing the efficiency of oil and gas industry enterprises in Uzbekistan. AIP Conf. Proc. 3331, 040075 (2025) https://doi.org/10.1063/5.0305986
27. Mukhitdinova, K.A, Vildanova, L.A Transport improvement of the method of assessing the attractiveness of investment in automotive enterprises. Published 2020 Engineering, Business, Economics, 171 Corpus ID: 218792573, https://DOI:10.31838/jcr.07.05.
28. Safarov J., Sultanova Sh., Dadayev G.T., Zulponov Sh.U. Influence of the structure of coolant flows on the temperature profile by phases in a water heating dryer. // IOP Conf. Series: Materials Science and Engineering. Dynamics of Technical Systems (DTS 2020). Vol.1029, 2021. №012019. P.1-11. doi:10.1088/1757-899X/1029/1/012019