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SOLAR ENERGY DEVELOPMENT IN THE CONTEXT OF TRANSITION TO A GREEN ECONOMY: ECONOMIC OPPORTUNITIES AND PROSPECTS FOR UZBEKISTAN

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Abstract

The purpose of the study is to identify the economic opportunities and limitations of solar energy development in Uzbekistan in the context of the transition to a green economy. Statistical analysis methods, data systematization, and a comparative approach to assessing the dynamics of solar power plant commissioning were applied. It was established that despite a high level of solar insolation and significant gross solar energy potential, the level of utilization of technical capacities remains low. It was proven that the introduction of government support measures, the attraction of international investors, and the implementation of large-scale projects gradually increase the share of renewable energy sources in the country's energy balance. The practical significance of the study lies in the possibility of using its results to develop programs for stimulating solar energy, optimizing energy policy, and improving Uzbekistan's energy security. The novelty of the work lies in the comprehensive assessment of the impact of solar energy projects on the country's economic development, considering regional specifics and the current state of infrastructure.

Keywords

solar energy, green economy, renewable energy sources, investments, energy efficiency, Uzbekistan.

РАЗВИТИЕ СОЛНЕЧНОЙ ЭНЕРГЕТИКИ В УСЛОВИЯХ ПЕРЕХОДА К «ЗЕЛЕНОЙ» ЭКОНОМИКЕ: ЭКОНОМИЧЕСКИЕ ВОЗМОЖНОСТИ И ПЕРСПЕКТИВЫ УЗБЕКИСТАНА

Аннотация

Целью исследования является выявление экономических возможностей и ограничений развития солнечной энергетики в Узбекистане в контексте перехода к «зеленой» экономике. В процессе работы применялись методы

статистического анализа, систематизации данных, а также сравнительный подход к оценке динамики ввода солнечных электростанций. Установлено, что, несмотря на высокий уровень солнечной инсоляции и значительный валовый потенциал солнечной энергии, уровень освоения технических возможностей остается низким. Доказано, что внедрение государственных мер поддержки, привлечение международных инвесторов и реализация крупных проектов позволяют постепенно наращивать долю возобновляемых источников энергии в энергобалансе страны. Практическая значимость исследования заключается в возможности использования его результатов для разработки программ стимулирования солнечной энергетики, оптимизации энергетической политики и повышения энергетической безопасности Узбекистана. Новизна работы состоит в комплексной оценке влияния проектов солнечной энергетики на экономическое развитие страны с учетом региональной специфики и текущего состояния инфраструктуры.

Ключевые слова

солнечная энергетика, зеленая экономика, возобновляемые источники энергии, инвестиции, энергоэффективность, Узбекистан.

Introduction. Modern trends in the global energy sector demonstrate a steady growth in electricity generation through renewable energy sources (RES). According to the International Renewable Energy Agency (IRENA), the installed solar generation capacity in the world increased from 40 GW in 2010 to 1047 GW by the end of 2022, which amounted to about 29% of the total capacity of all renewable energy sources [1]. The leading positions in the established solar energy capacity are occupied by China (393 GW), the European Union (209 GW), the USA (142 GW), Japan (78 GW), and India (67 GW) [2]. The dynamics in Central Asia are insignificant, but Uzbekistan is demonstrating rapid development in this area. According to the Ministry of Energy of the Republic of Uzbekistan, the total capacity of commissioned solar power plants at the end of 2023 reached 500 MW, and by 2030, this figure is planned to reach 5000 MW [3].

Despite the significant potential of solar energy due to the average annual solar standing of 1500-1600 kWh/m2 and more than 320 solar days per year [4], the level of its practical implementation remains relatively low. In the energy balance structure, renewable energy sources account for less than 10%, while natural gas accounts for more than 80% [5]. This is due to the high capital intensity of solar projects, inadequate infrastructure, as well as institutional and financial barriers.

Analysis of scientific publications allows us to identify several areas of discussion in the field of economic valuation of solar energy. Some researchers consider renewable energy sources as a factor reducing the energy vulnerability of developing countries and ensuring macroeconomic stability [6]. Others point to significant budgetary burdens associated with subsidizing such projects [7]. Particular attention is paid to public-private partnerships and attracting foreign investment, which are considered a key tool for intensifying energy transformation [8].

The identified gaps in scientific research during the analysis allow us to state that the economic consequences of integrating solar generation into the structure of Uzbekistan's gas-oriented energy system have not been sufficiently studied. The long-term effects of reducing the cost of electricity for industrial enterprises, as well as the optimization of financial instruments for stimulating private investment in solar energy, remain open.

The scientific problem is formulated as follows:

1. What are the economic benefits of solar energy development for the stability of Uzbekistan's energy system?

2. To what extent does the introduction of solar generation contribute to reducing electricity costs in the industrial sector?

3. What financial mechanisms are most effective in ensuring investment activity in the solar energy sector?

The novelty of the research lies in the comprehensive assessment of the influence of solar energy on the parameters of economic security of Uzbekistan, taking into account the specifics of its energy balance. The research hypothesis is that the development of solar energy will lead to a reduction in energy risks, a decrease in dependence on hydrocarbon imports, and a reduction in electricity costs for industrial consumers.

The goal is to assess the economic consequences of developing solar energy in Uzbekistan and identify ways to improve financial incentives for investors.

Tasks:

1. Examine the impact of solar energy on the country's energy sustainability.

2. Evaluate the impact of solar generation on the reduction of electricity costs for industry.

3. Identify the financial instruments that ensure the inflow of investments into the solar energy sector.

Materials and Methods

The research is aimed at conducting a comprehensive economic assessment of the consequences of the integration of solar energy into the energy system of

Uzbekistan, as well as identifying the most effective financial instruments that ensure the stimulation of private investment in this sector. In accordance with the set goal, the influence of solar generation development on the country's energy sustainability was analyzed, the possibilities of reducing the costs of industrial consumers were assessed, and the mechanisms for forming investment activity in the field of solar energy were investigated.

Quantitative and qualitative methods were used in carrying out the research, which is due to the need to combine macroeconomic analysis, project assessments, and an institutional approach. Statistical data from the International Renewable Energy Agency, the International Energy Agency, the Ministry of Energy of the Republic of Uzbekistan, the Asian Development Bank, and the World Bank were used as a source. These sources provide access to up-to-date information on the dynamics of solar energy capacity, energy consumption structure, and investment project indicators at both global and regional levels.

To quantitatively assess the influence of solar generation on energy stability, an economic-statistical analysis was used, which involves processing data on changes in the installed capacity of photovoltaic stations, the level of insolation, and the share of renewable energy sources in the structure of electricity production and hydrocarbon consumption. This approach allowed for recording the current level of solar energy development and comparing it with the target indicators outlined in the strategic documents of the Republic of Uzbekistan.

The analysis of solar generation's impact on industrial consumers' costs relied on economic modeling methods, including the calculation of electricity production costs using the full life cycle method (Levelized Cost of Energy, LCOE). The calculation parameters were capital investments, operating costs, projected tariffs, and solar generation production volumes, reflecting both global trends and Uzbekistan's regional characteristics. The LCOE approach is an international standard for assessing the economic efficiency of energy projects, allowing for the extrapolation of the obtained results for other projects under similar conditions.

To identify factors of investment activity, specific projects implemented in Uzbekistan with the participation of foreign companies were studied: Masdar, Total Eren, Phanes Group, SkyPower Global, Graess Energy. The study of these projects made it possible to assess the effectiveness of public-private partnership mechanisms, identify key incentives for attracting capital, and identify institutional limitations hindering the expansion of solar energy.

The regulatory and legal environment analysis method was used to assess the impact of state energy policy on the solar generation economy. The focus is on the provisions of the Concept for the Development of Energy of the Republic of

Uzbekistan until 2030, preferential lending programs, tax preferences for investors in renewable energy sources, and the procedure for concluding energy service contracts.

Data collection was carried out by studying official reports, analytical publications of international organizations and government structures of Uzbekistan, including the Ministry of Energy and relevant subdivisions of the Cabinet of Ministers. Using information from primary sources ensured the reliability of the analysis and the representativeness of the results. Methodological limitations are related to the limited availability of detailed data on the operational cost structure of operating solar power plants in Uzbekistan. In addition, high price volatility for photovoltaic modules and currency fluctuations can adjust the economic efficiency of projects in the short term, which requires clarification in the context of practical implementation of the developed approaches.

The application of comprehensive methodological tools, including economic and statistical analysis, life cycle cost estimation methods, regulatory and legal environment research, and investment practice studies, has ensured the reliability of the obtained conclusions and identified key determinants of the economic sustainability of solar energy in Uzbekistan.

3. Results

The purpose of this study was to identify the current state, economic effects, prospects, and problems of developing solar energy in Uzbekistan in the context of the national energy strategy and global decarbonization trends. During the analysis, the potential of renewable energy sources (RES), the dynamics of installed capacity, the structure of electricity consumption, investment activity, the practical results of the implementation of projects, as well as the long-term directions of the state energy policy were studied.

The gross potential of renewable energy sources in Uzbekistan is estimated at 117,973 million tons of oil equivalent. Of this volume, 50,973 million tons are solar energy, which is 99.7% of the total potential of all renewable energy sources in the country. The technical potential of solar energy reaches 176.8 million tons of oil equivalent (98.6% of the technical potential of renewable energy sources), however, in fact, only 0.3% - 0.6 million tons of oil equivalent has been mastered for 2022. This gap indicates an extremely low level of practical realization of solar potential, despite favorable climatic conditions: 300 sunny days a year, average annual insolation 1500-1600 kWh/m2. Particularly promising regions are Bukhara, Kashkadarya, Surkhandarya regions, and the southern part of Navoi region, where the level of solar radiation reaches 2028 kWh/m^2.

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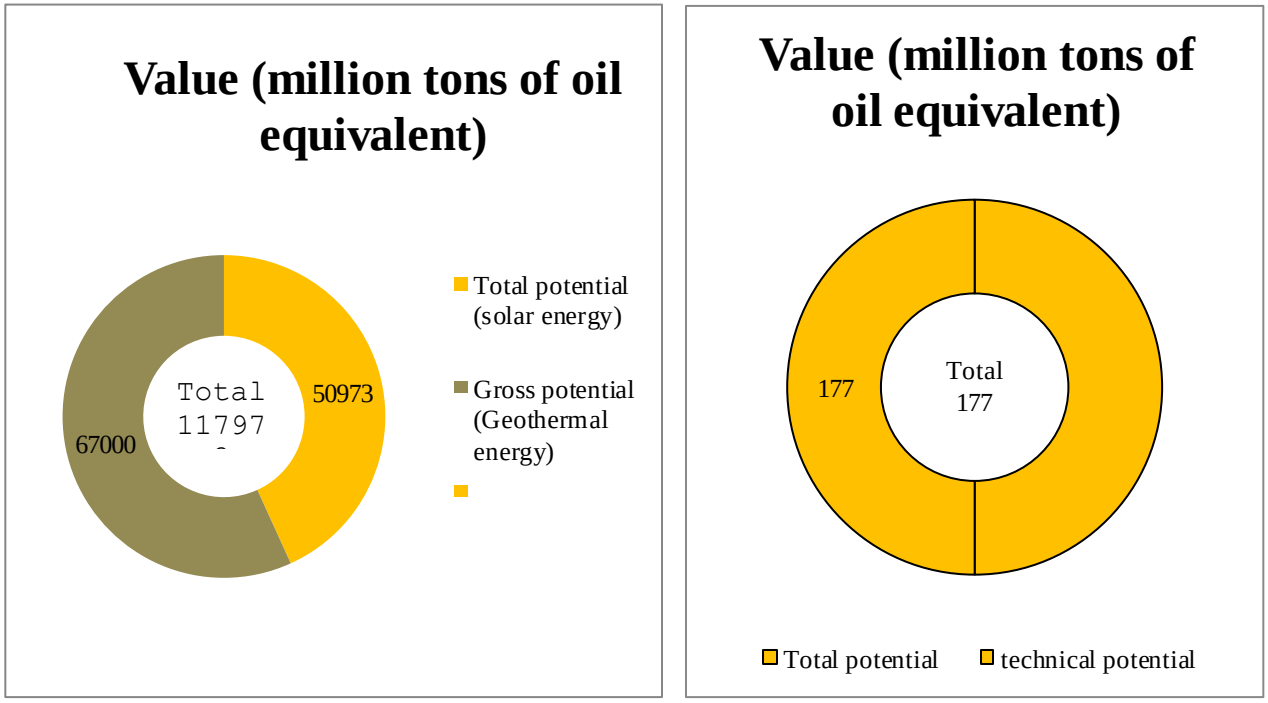

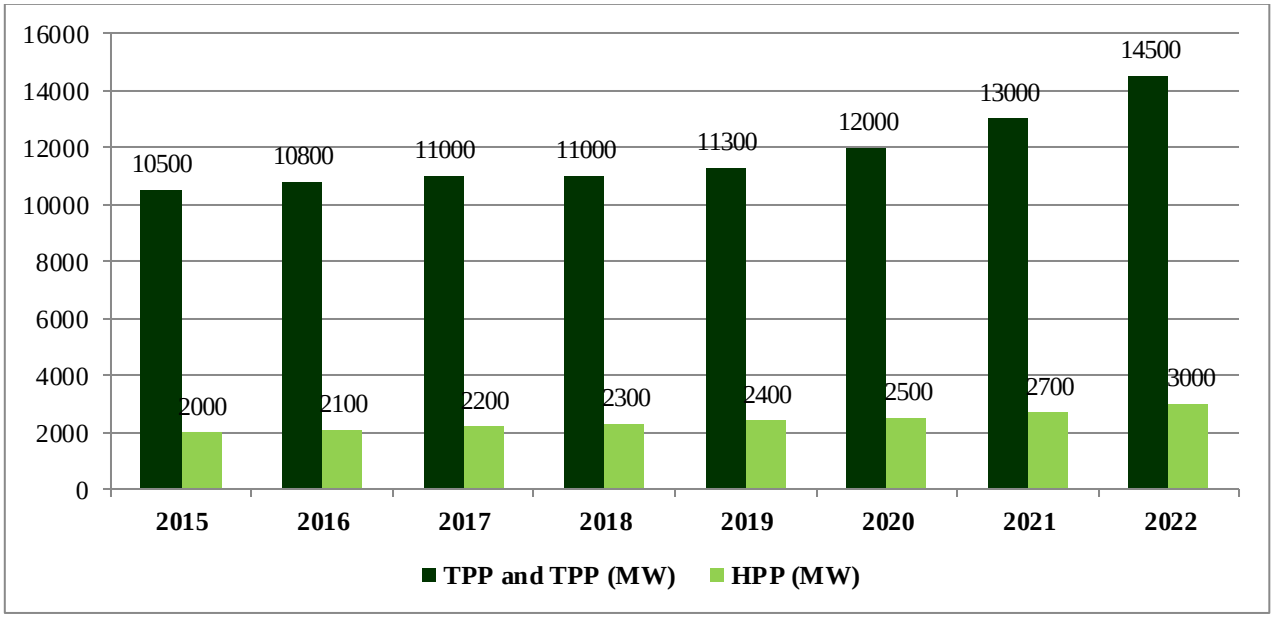

FIGURE 1 - Uzbekistan's RES potential in 2022

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In accordance with the Concept for Ensuring the Electricity Supply of the Republic of Uzbekistan for 2020-2030, the installed capacity of solar power plants should reach 5 GW, wind power plants - 3 GW, and the share of renewable energy sources in the energy balance will increase to 25%. The total installed electricity capacity will increase from 12.9 GW in 2019 to 29.3 GW by 2030, which implies an annual increase of approximately 1.5 GW. At the same time, the share of

traditional gas generation will decrease, giving way to solar, wind, and nuclear power plants.

FIGURE 2 - Structure of installed capacity 2019-2030

In fact, there is a gradual increase in solar generating capacities. In 2019, the installed capacity of the SES was 0 MW. In 2021, the first large facilities were commissioned: "Navoi" SES (100 MW), "Samarkand" SES (100 MW), "Tutli" SES (100 MW). In 2023, large-scale power plants were launched: "Sherobod" SES (457 MW), SES in Kattaqo'rg'on district of Samarkand region (220 MW), SES in G'allaorol district of Jizzakh region (220 MW). The total volume of investments in the sector amounted to $15.4 billion, of which $13.4 billion are private investments. Among the largest investors are Masdar (UAE), Total Eren (France), Phanes Group (UAE), SkyPower Global (Cayman Islands), Graess Energy (Germany).

Parallel to the introduction of new capacities, electricity consumption is increasing. In 2022, it reached 69.6 billion kWh. The leaders in consumption were Tashkent region (8319,9 million kWh), Navoi region (6648.8 million kWh), and

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Fergana Valley, which is related to the concentration of industry. The increase in electricity consumption by an average of 35% over the past five years creates additional pressure on the grid and emphasizes the importance of accelerated development of solar energy.

FIGURE 3 - Electricity consumption by regions in 2022

The production of natural gas, the dominant energy source in the country, shows volatility: 2019 - 100.2 billion m3, 2020 - 80.9 billion m^3, 2021 - 108.3 billion m^3, 2022 - 98.7 billion m^3, 2023 - 90.6 billion m^3. Reducing gas production requires diversification of the balance and strengthening the role of renewable energy sources.

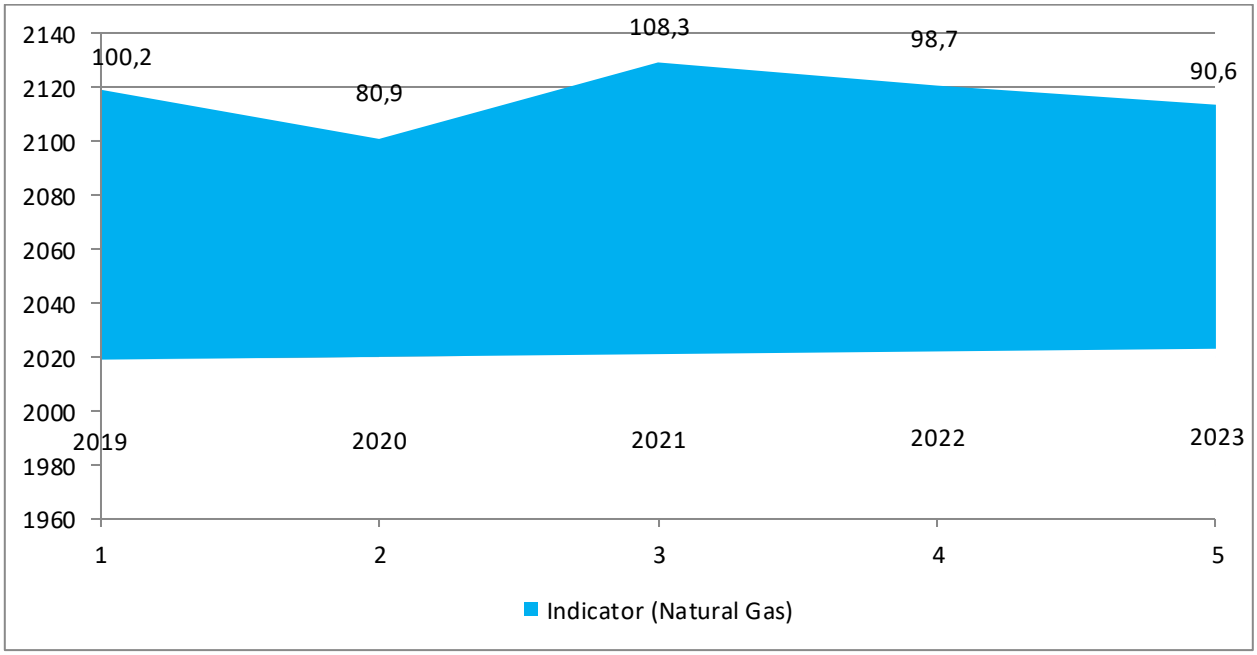

FIGURE 4 - Natural gas production 2019-2023

The production of electricity from solar and wind sources began to be recorded from 2015, but until 2020, it remained symbolic. In 2020, production reached 15.5 million kWh, and with the launch of large power plants, it reached 750 million kWh in 2023.

Table 1.

Dynamics of solar energy development and key economic indicators

Indicator	**2019**	**2020**	**2021**	**2022**	**2023**
Installed capacity of solar power plant, MW	0	100	200	380	874
Commissioning of new capacities, MW	0	100	100	180	494
Investment volume, USD million	0	100	300	650	1 200
Electricity production, million kW h	0	15.5	160	330	750
Natural gas savings, million cubic meters	0	0	48	150	420

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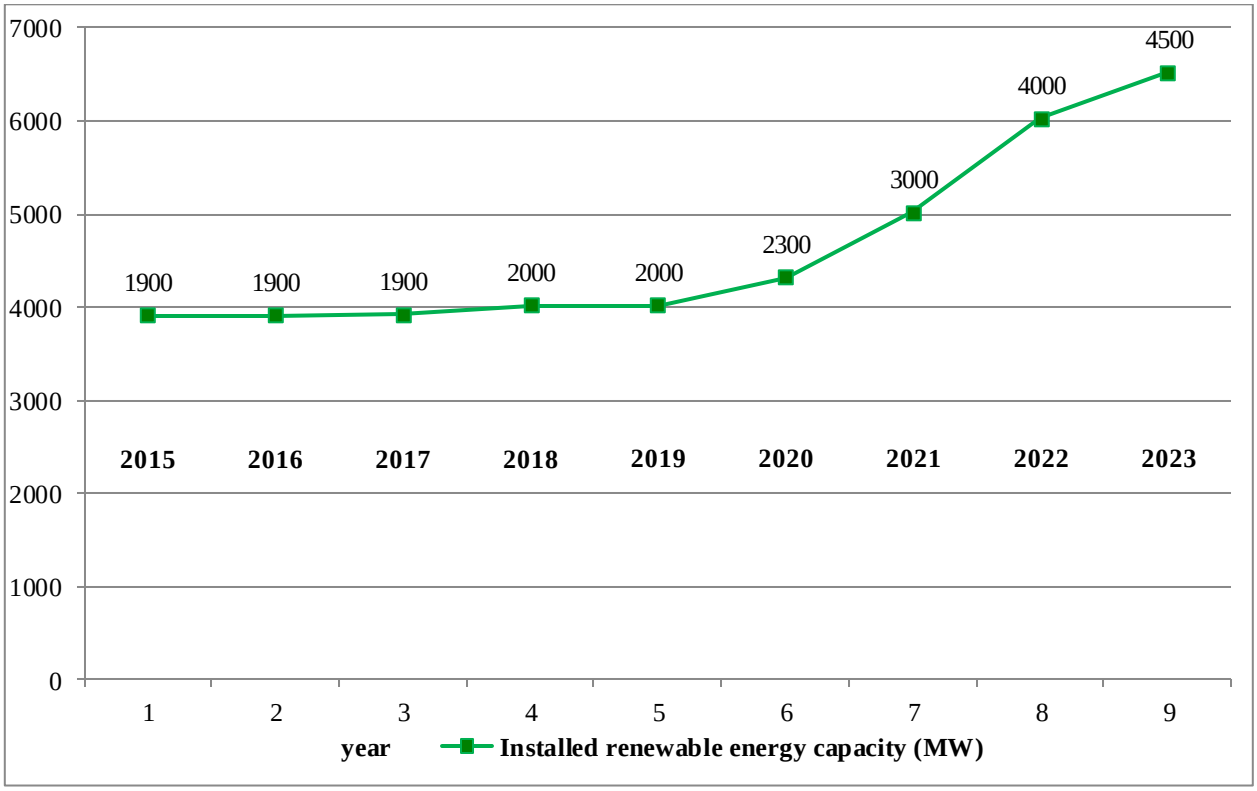

FIGURE 6 - Production of electricity from alternative sources 2015-2023

The obtained results show that despite the initiated transformations, the current growth rate of solar energy is lagging behind the target indicators set until 2030. It is necessary to intensify the commissioning of capacities, improve energy storage systems, and further stimulate private investment to achieve the goals set within the framework of the green economy.

4. Discussion

The research results, reflecting the current state and prospects for the development of solar energy in Uzbekistan, are consistent with the conclusions of a number of researchers who have studied similar issues. In particular, previously published works emphasize the high potential of solar energy in the country, due to favorable climatic conditions, which is confirmed by data on the gross and technical potential of renewable energy sources [9]. However, as noted in several studies, despite the obvious advantage, the degree of solar potential utilization remains extremely low, correlating with the actual utilization indicators of only 0.3% of the technical potential identified in this study [10].

The works of Uzbek authors emphasize the importance of state support and attracting foreign investment, noting the positive impact of cooperation with international companies and financial institutions such as Masdar, Total Eren, Phanes Group, and the World Bank [11]. The data obtained during this study on

large-scale investment projects in Navoi, Samarkand, Jizzakh, and Surkhandarya regions confirm this conclusion.

Comparison of the results with studies by foreign authors analyzing the experience of Germany, Spain, and China shows that a key factor in the successful development of solar energy is the developed infrastructure and the availability of energy storage systems [12]. In Uzbekistan, these aspects remain insufficiently developed, which is reflected in the identified problems related to the integration of SES into the general energy system and the conservation of excess energy. Similar challenges are also noted in Central Asian countries, such as Kazakhstan, where the processes of transition to renewable energy sources are accompanied by similar infrastructural difficulties [13].

In addition, a number of studies devoted to the energy transition in developing countries emphasize the importance of gradually reducing subsidies for traditional energy sources, which in the long term creates favorable conditions for renewable energy sources [14]. This study revealed Uzbekistan's continued dependence on natural gas, which confirms the conclusions of other authors about the need to change the structure of energy policy.

It should be noted that the increase in electricity consumption identified during this study aligns with the forecasts of national experts, which indicate the active development of industry and an increase in the number of households [15]. However, as emphasized in foreign publications, under conditions of increasing energy consumption, the development of renewable energy sources alone without modernizing the network infrastructure can lead to a decrease in the reliability of electricity supply [16].

Interpretation of the obtained data in the context of existing scientific works indicates that Uzbekistan is at the initial stage of active development of solar energy. At the same time, the experience of leading renewable energy sources countries indicates the need for a comprehensive approach, including the development of infrastructure, the introduction of energy saving systems, and the improvement of state regulation, which will increase the effectiveness of the implementation of the set tasks.

5. Conclusion

The conducted research made it possible to identify the significant potential for the development of solar energy in Uzbekistan, which corresponds to the set goal - to assess the economic opportunities for the transition to "green" energy and the integration of solar power plants into the national energy system. All the tasks set have been achieved: a high degree of solar insolvation as a key factor has been substantiated, the scale of attracted investments has been revealed, the dynamics of

commissioning new generating capacities have been analyzed, and infrastructural and financial barriers have been identified.

The practical significance of the results lies in the possibility of their use in optimizing state energy policy, developing incentive mechanisms for investors, and increasing energy efficiency in production. The obtained data can be integrated into sustainable development programs, taking into account the needs of regions with high energy consumption and a shortage of generating capacities.

The prospects for further research are related to assessing the economic efficiency of implementing energy storage systems, modeling the impact of solar power plants on reducing the cost of imported hydrocarbons, as well as studying international practices for creating integrated renewable energy sources networks in a developing economy.

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