**МРНТИ** 06.8112
**УДК** 621.3.001.895
**DOI** 10.58319/26170493_2025_1_87

# INNOVATIVE DEVELOPMENT OF THE ELECTRIC POWER INDUSTRY IN CONDITIONS OF UNCERTAINTY WORLD PRACTICE AND KAZAKHSTAN

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**ABSTRACT**. The article discusses current issues of the managing the innovative development of the electric power industry in Kazakhstan, as well as the possibilities and difficulties of bringing the country's electric power industry to an innovative type of development. Particular attention is paid to the disclosure of the role of renewable energy sources (wind, solar, water and bioenergy) in the development of the country's energy sector, the opportunities and innovative potential for their development.

**KEYWORDS:** innovation, management, energy, science, natural resources, technology, renewable energy sources.

# ҮНКЕРТЕЙНДЕР ЖАҒДАЙЫНДАҒЫ ЭЛЕКТЭНЕРГЕТИКАСЫ САЛАСЫНЫҢ ИННОВАЦИЯЛЫҚ ДАМУЫ ӘЛЕМДІ ТӘЖІРИБЕ ЖӘНЕ ҚАЗАҚСТАН

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**АҢДАТПА.** Мақалада Қазақстанның электр энергетикасының инновациялық дамуын басқарудың өзекті мәселелері, сондай-ақ еліміздің электр энергетикасын дамудың инновациялық түріне шығарудың мүмкіндіктері мен қиындықтары қарастырылған.Жаңғыртылатын энергия көздерінің (жел, күн, су және биоэнергетика) еліміздің энергетика саласын дамытудағы рөлін, оларды дамытудың мүмкіндіктері мен инновациялық әлеуетін ашуға ерекше назар аударылады.

**ТҮЙІН СӨЗДЕР:** инновация, менеджмент, энергетика, ғылым, табиғи ресурстар, технология, жаңартылатын энергия көздері.

# ИННОВАЦИОННОЕ РАЗВИТИЕ ЭЛЕКТРОЭНЕРГЕТИКИ В УСЛОВИЯХ НЕОПРЕДЕЛЕННОСТИ: МИРОВАЯ ПРАКТИКА И КАЗАХСТАН

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**АННОТАЦИЯ.** В статье рассматриваются актуальные вопросы управления инновационным развитием электроэнергетической отрасли Казахстана, а также возможности и трудности вывода электроэнергетики страны к инновационному типу развития. Особое внимание уделено раскрытию роли возобновляемых источников энергии (энергии ветра, солнца, воды и биоэнергии) в развитии энергетики страны, возможностей и инновационного потенциала для их развития.

**КЛЮЧЕВЫЕ СЛОВА:** синновация, энергетика, наука, природные ресурсы, технологии, возобновляемые источники энергии.

**INTRODUCTION**. Geopolitical events of recent years, the pandemic and its post-recovery period, emerging challenges in global energy, and significant issues such as the depletion of fossil hydrocarbon fuel reserves, sharp fluctuations in energy resource prices, and ensuring planetary environmental safety amid growing energy consumption have significantly influenced the innovative development of the global economy.

Modern information technologies and artificial intelligence create opportunities and conditions for qualitative changes in the development of the global economy, including the energy sector. Indicators of technological progress in global energy continue to grow under the influence of innovation waves driven by digital technologies and scientific advancements (supercomputers are becoming faster and more energy-efficient; the cost of low-emission energy technologies, such as solar and wind energy, is decreasing; production of robots and electric vehicles is rising).

However, the adoption of some technologies remains limited. Kazakhstan has set itself the complex strategic task of elevating its national economy to a qualitatively new level, transitioning to an innovative development model, including in its leading sector—electric power engineering. Given the growing global energy deficit, Kazakhstan urgently needs "reliable and environmentally clean energy sources."

At the state level, the task has been defined to "critically rethink the organization of raw material industries, approaches to managing natural resources," ensure "environmental friendliness and efficiency of energy producers," and advance progress in "alternative, 'clean' energy" [1].

**MATERIALS AND METHODS OF RESEARCH.** Current practice demonstrates that no national energy sector can remain self-sufficient based solely on existing production factors, technologies, and capital needs. To remain competitive in the modern world, it is essential not only to rely on domestic natural, economic, technological, and intellectual resources but also to consider the priorities and norms established by key players in the global economy.

A critical source of information for developing a national economic strategy and evaluating the effectiveness of innovation activities is the annually published Global Innovation Index (GII) report. This report serves as a methodological tool for conducting comparative analyses of countries' progress in innovation over specific periods.

The annual monitoring of 130 countries in the GII provides a ranking based on dozens of parameters that extend beyond traditional innovation indicators. For instance, the GII 2023 analyzes innovation performance against the backdrop of economic and geopolitical uncertainty, including slow post-pandemic recovery, high interest rates, and geopolitical conflicts [2].

In 2022–2023, innovation investment dynamics showed mixed trends amid numerous challenges and a decline in funding for innovation. A sharp reduction in the monetary volume of venture investments reflected worsening conditions for risk financing. The prospects for venture funding in the coming years remain uncertain due to tighter monetary policies and heightened geopolitical risks. To study the level of innovation activity in Kazakhstan, including in the energy sector, this article uses data and comparative analyses from GII reports (2013–2023), with a focus on GII 2023. This approach helps identify challenges and opportunities for innovative solutions to advance the national energy sector.

**RESULTS AND DISCUSSION.** Innovations in the electricity sector, as a leading industry in any economy, are typically not only national but also global in nature. The innovative development of the electricity sector is viewed as a transition from the existing model (based on hydrocarbon combustion for energy generation, environmental pollution, power transmission via overhead lines, and human labor in toxic production conditions) to a qualitatively new stage.

This new stage relies exclusively on renewable and hydrogen energy, incorporating modern technologies such as digital, nano, wave, and others. Currently, the global electricity sector is at a pivotal stage of its development. The key drivers of this transition are decarbonization, digitalization, and decentralization.

The idea of environmental pollution and the exhaustibility of natural resources, first proposed by the Club of Rome, initiated targeted actions by scientists, major energy companies, governments, and society to harness natural conditions as energy sources (now termed "renewable energy sources" or RES).

Recognizing the potential of RES for societal development represents one of the most significant

innovations. Today, the global electricity sector sees the large-scale development of RES as a solution to ecological and economic challenges, owing to their environmental friendliness, flexibility, cost-effectiveness, and inexhaustibility. Well-known and actively researched RES include wind, hydro, tidal, wave, solar, geothermal, and bioenergy. RES are being implemented worldwide, with technologies becoming increasingly advanced and affordable.

Current trends in the innovative development of the electricity sector indicate an ongoing industry transformation. Over the past decade, RES have seen rapid growth, characterized by increased energy volumes, reduced costs, rising investments, and technological advancements (Fig. 1). RES technologies have become mainstream and competitive alongside fossil fuels and nuclear energy. By 2023, RES accounted for 29% of global electricity generation, up from 26.5% in 2017 [3].

As practice shows, during the pandemic, post-pandemic period, and significant geopolitical upheavals, there is a transformation of the global innovation landscape not only within the group of leading innovative economies but also on a broader scale. This is evidenced by data from the annual report "Global Innovation Index," which is a key source of information for evaluating the effectiveness of innovative activity in various economies worldwide.

According to GII-2023, innovation leaders (the top 25 economies) demonstrate balanced and high scores across all metrics. Switzerland remains the undisputed global leader in innovation, holding the top position in the categories "Knowledge and Technology Outputs" and "Creative Outputs." Sweden rose to second place, surpassing the USA, and leads in the category "Business Sophistication" (1st place), ranks second in "Infrastructure" (2nd place), and third in "Human Capital and Research" (3rd place). [2; pp. 11-13.]

The GII-2023 report highlights seven regions, each with three leading innovative economies. For example, in the "Europe" region, the leaders are Switzerland, Sweden, and the United Kingdom, while in the "Southeast Asia, East Asia, and Oceania" region, they are Singapore, South Korea, and China. In Central and South Asia, India ranks first in "Human Capital and Research" (48th place) and "Knowledge and Technology Outputs" (22nd place). Iran retains second place in the region, ranking 62nd overall. The country is a regional leader in market development (19th place), creative outputs (43rd place), and leads in the "Trademarks" category (1st place).

Kazakhstan, ranked 81st overall, holds third place in this region. Kazakhstan leads in "Infrastructure" (59th place) due to high results in areas like "Government Online Services" (8th place) and "Internet Inclusion" (15th place). In the "Central and South Asia" region, Kazakhstan ranked third as a new participant for the first time. In the GII 2023 ranking, Kazakhstan holds 81st place (compared to 78th in 2017), trailing behind Vietnam (46th), Ukraine (55th), Moldova (60th), Georgia (65th), Mongolia (68th), Armenia (72nd), Tunisia (79th), and Belarus (80th).

Moreover, in terms of innovation efficiency at different income levels in 2023, Kazakhstan did not make it into the group of countries exceeding expectations based on their level of development

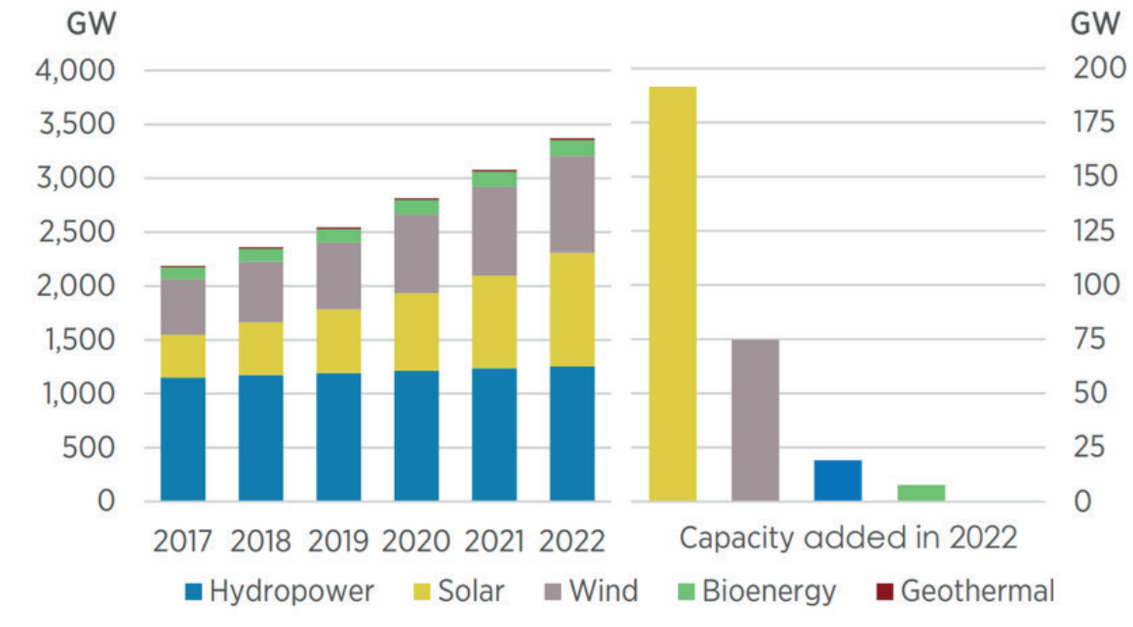


**Figure 1 - Growth in Renewable Energy Capacity, 2017–2022**

(countries like India, Vietnam, Ukraine, Mongolia, Uzbekistan, etc., which belong to the above-average income group); Kazakhstan also did not qualify for the "Indicators Corresponding to Level of Development" category (which includes Iran, Egypt, Sri Lanka, Cambodia, Bangladesh, Kyrgyzstan, Nigeria, Tajikistan, etc.).

Kazakhstan falls into the "All Other Economies" group regarding innovation efficiency. Based on the ratio of innovation inputs to outputs in 2023, Kazakhstan is marked as inefficient [2]. As seen from the report, Kazakhstan still has much work ahead in many indicators (including global R&D performers, quality of scientific publications, university standards, export of high-tech services, etc.). For instance, Uzbekistan joined the group of middle- and low-income countries that achieved the most progress—more than 20 positions—outside the top 65 leading countries but within the top 100 over the past decade (Uzbekistan ranks 82nd) [2; pp. 26-28.].

Considering Uzbekistan's high innovation activity dynamics, it can be assumed that Kazakhstan may lose its positions to Uzbekistan by 2024-2025. The results of the GII-2023 ranking highlight the need to support numerous positive changes in developing countries' development over the past twenty years.

For example, a clear trend emerged of integrating innovation systems into the agendas of policymakers, legislators, and participants in innovation activities in developing countries. Attention is required for organizing and systematically functioning innovation ecosystems, preventing disruptions in global supply chains affecting emerging innovation systems in middle- and low-income countries. Subsequently, the GII authors plan to track how changes in GII indicators at the country or regional level impact innovation activities, identifying which are temporary and which are more long-term.

For Kazakhstan, addressing energy diversification and security issues, as well as searching for and implementing innovative technologies and clean energy sources, remains relevant. Currently, Kazakhstan operates 220 power plants, including 144 renewable energy facilities with a capacity of 2.8 GW. Overall, as of January 1, 2024, the total installed capacity amounted to 20.4 GW. In 2023, electricity consumption reached 115 billion kWh (compared to 112.9 billion kWh in 2022), while domestic production totaled 112.8 billion kWh. Electricity imports from neighboring countries amounted to 3.4 billion kWh, with exports at 1.4 billion kWh.

Thus, Kazakhstan still does not fully meet its electricity needs, importing from neighboring countries. The average transmission loss rate (5.1 billion kWh) was 11.2%, with a high level of equipment wear (65%). The existing imbalance in Kazakhstan's energy system leads to disruptions and electricity shortages for large industrial enterprises during peak periods, as well as mass power outages in certain regions during the winter of 2022-2024.

It is known that Kazakhstan, due to its geographical and climatic features, possesses a vast territory (9th largest in the world) and significant potential for wind (920 billion kWh annually) and solar energy (2.5 billion kWh annually). However, in 2024, coal (53.3%) and gas (24.8%) remain the primary sources of electricity generation, with renewables accounting for only 11.8% (see Fig. 2: Structure of Electricity Generation).

According to the given diagram, Kazakhstan plans to increase the share of renewable energy sources (RES) to 24.4% by 2035, while reducing the share of coal to 34.3% [4]. In the field of RES, it is planned to commission 592 MW of green generation by

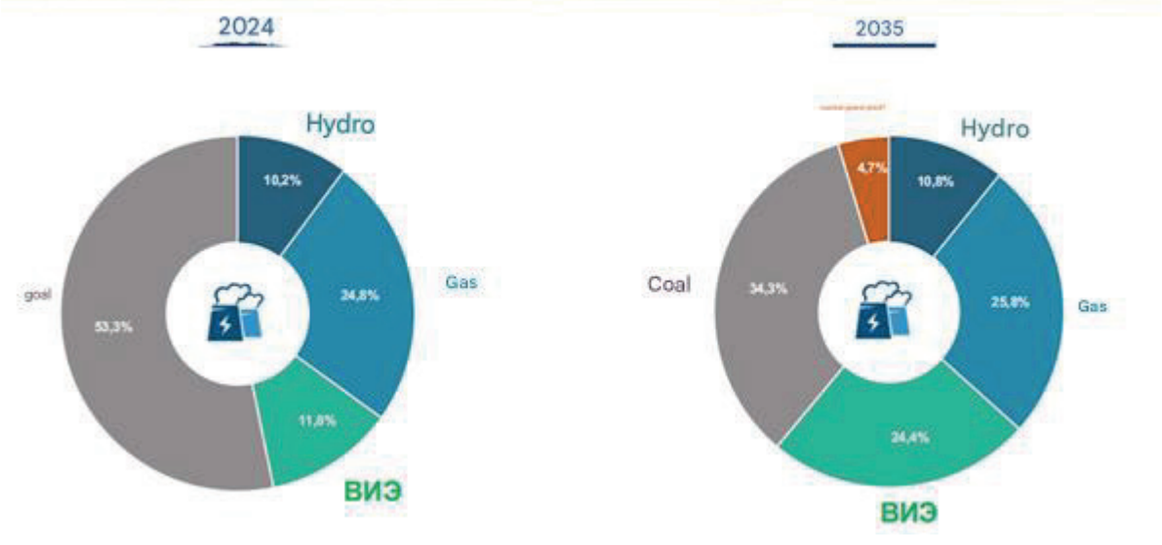


**Figure 2 - Structure of electricity generation in the energy sector**

2027. To achieve a 15% share of renewable energy sources by 2030, large-scale projects with strategic investors such as Total Energies, Acwa Power, and Masdar are planned.

This will fully ensure Kazakhstan's electricity needs by 2030 and allow for energy exports to neighboring countries on a larger scale. The construction of new gas-fired power plants is planned in the cities of Kyzylorda, Shymkent, Taraz, Aktau, Atyrau, and Aktobe [5-6].

Under these conditions, it is important to ensure monitoring and control over the implementation of investment programs by regional electric grid companies, as well as coordination of their activities. In order to implement tasks and projects in the field of RES, in 2024, the Law of the Republic of Kazakhstan "On Amendments and Additions to Certain Legislative Acts of the Republic of Kazakhstan on Issues of Supporting the Use of Renewable Energy Sources and Electricity" was adopted. This law aims to further improve mechanisms for supporting and developing the energy sector [7].

In particular, owners of small-scale RES (with a capacity of no more than 200 kilowatts) have been granted the right to use electricity and/or thermal energy generated by such facilities for their own needs and sell surplus electricity to energy supply organizations. Surplus electricity will be purchased by the energy supply organization at a maximum price (without differentiation by consumer groups), set by the Committee for the Regulation of Natural Monopolies under the Ministry of National Economy, along with a number of other measures. In the context of decarbonization and the transition to cleaner energy sources, nuclear energy (which will be the subject of another article) plays a key role in reducing the country's dependence on coal and natural gas.

Nuclear energy provides stable base-load electricity generation, which helps compensate for the intermittency of renewable energy sources. A sociological study conducted by the author of this article in 2020, titled "Innovative Behavior of Companies in Kazakhstan's Electric Power Industry," revealed the inefficiency of the existing innovation model of companies in Kazakhstan's electric power industry. Managerial decisions were found to focus on purchasing equipment and technology abroad, relying solely on internal capabilities, insufficient funding, weak cooperation with key elements of the national innovation system, and ineffective innovation management [8].

The study demonstrated that company leaders are familiar with most methods of managing innovative development but tend to use the simplest management approaches, such as compliance with technical regulations and standards, as well as employee development programs.

However, only 47% of respondents reported using knowledge management methods—a key element of innovation management. Significantly less frequently, energy companies in the country acquired new technologies (reported by 15% of respondents).

It is important to look at best global practices, organize the work of in-house research centers and independent scientific laboratories, support university research, conduct joint studies with other companies, and so on. Of great scientific and practical interest is the experience of the transnational energy group IBERDROLA, which ranks among the top five largest energy companies in the world and is a global leader in wind energy production. Iberdrola has developed and implemented systems of innovation management, innovation incentives, and knowledge management.

The latter, for example, involves creating value and fostering a culture of continuous transformation, mechanisms for internal knowledge communication to disseminate innovative knowledge and experience, intellectual and property rights management, and innovation process management. The innovation management system includes a monitoring system and technological searches that can identify opportunities and needs for innovation in processes or services, thereby anticipating technological changes in the market [9].

Attention is drawn to ongoing global scientific developments in the transmission of electricity through magnetic and other ultrasonic waves. While such methods are currently very expensive and complex—characteristic of most innovations—over time, with the adoption of technologies, their application becomes more accessible and less costly [10]. Russian scientists have developed an innovative algorithm for managing electrical grids, which will allow for more economical resource consumption and more efficient electricity distribution [11].

The prospects for innovative activity in Kazakhstan's energy sector will require a shift in priorities from quantitative to higher-quality indicators of electricity production. For instance, it is crucial for Kazakhstan to promote the widespread development of digitalization, which can reduce the cost of electricity through automated diagnostics and identification of problematic "points" or "zones" across the entire system of generation, transmission, and distribution. It can also help prevent potential accidents, significantly reduce losses in electrical networks, update technologies, optimize production processes, and enhance the efficiency of production and business operations.

**CONCLUSION**. The era of the hydrocarbon-based global economy is gradually giving way to a new period where societal life will be based on renewable energy sources, digital and nanotechnologies, and

the total automation of production in the electric power industry. Transitioning from the extraction and use of hydrocarbon resources to the utilization of unlimited reserves of renewable energy sources can be considered an optimal solution for addressing global energy challenges in a more economical and environmentally friendly manner.

During this period of significant change, almost all countries will face complex tasks related to energy security, though the nature of these challenges may vary depending on the region and available resources. Despite having substantial hydrocarbon reserves, Kazakhstan recognizes the need to transform its existing electric power industry from traditional to "green," as evidenced by recently adopted legislative acts. However, the country's electric power sector still exhibits low innovation activity, reliance on internal capabilities, insufficient funding, weak cooperation with key elements of the national innovation system, a focus on purchasing equipment abroad, and ineffective innovation management. In this context, it is crucial for Kazakhstan to unite the potential of all participants in innovation activities (government bodies at all levels, business structures, research universities, innovation clusters, etc.) to assess the effectiveness of innovation activities in the industry and the country as a whole.

Based on a thorough analysis, it is necessary to identify the full range of internal innovation capabilities and determine ways to overcome difficulties and obstacles present in Kazakhstan's economy, including the electric power industry. Ensuring flexible management of the electric power industry can become a source of competitive advantage for both individual companies and the industry as a whole.

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