# Resilient Energy System – Energy Storage, Smart Grids, and Efficiency

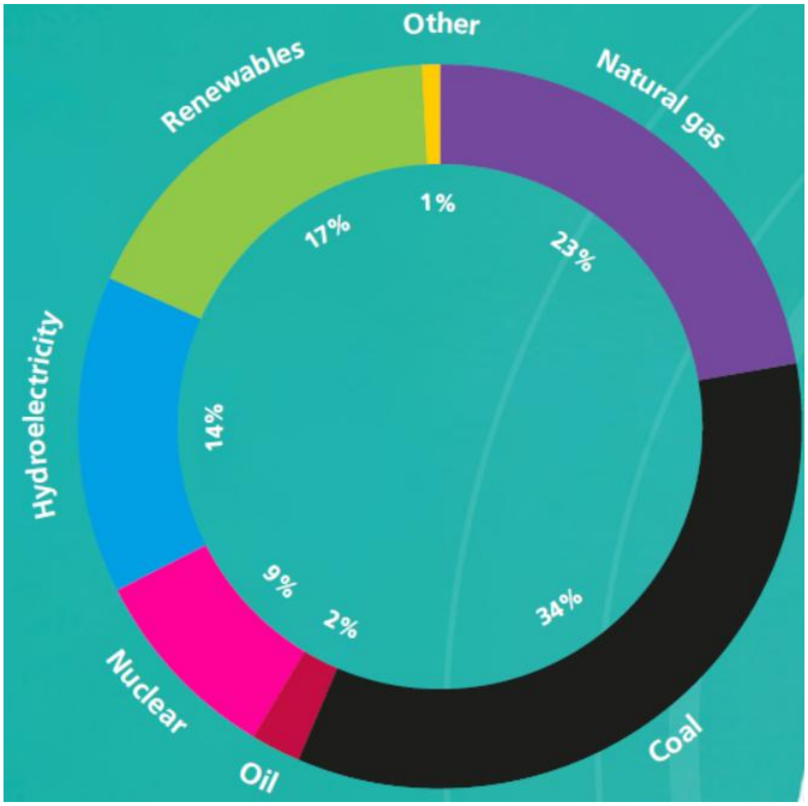
## Introduction

Since gaining independence in 1991, Kazakhstan has achieved remarkable economic growth, transforming its GDP from approximately $24.9 billion in 1992 to $288 billion in 2024. This represents more than an 11-fold increase in nominal GDP [and more than a 7-fold increase in real GDP] over three decades, demonstrating the country's successful economic development trajectory. A crucial factor enabling this economic growth was the capacity buffer built during the Soviet era. This inherited electricity infrastructure provided the foundation to power Kazakhstan's robust economic growth without experiencing major electricity supply disruptions. The energy sector's reliability has supported Kazakhstan in attracting over $400 billion in foreign investment since independence. Kazakhstan now faces an even more ambitious target: doubling GDP to $450 billion by 2029.

However, achieving this goal requires fundamental transformation of the country's energy infrastructure to meet 21st-century demands, particularly as the world enters the artificial intelligence era and Kazakhstan strives to become Central Asia's regional AI hub. Beyond technological ambitions, continuous urbanization and population growth are simultaneously driving electricity demand upward. To successfully balance these converging pressures, Kazakhstan's legacy power systems should undergo comprehensive modernization. Just as electricity serves as the lifeblood of a modern economy, Kazakhstan's ability to achieve its 2029 economic targets depends critically on building a resilient, efficient, and modern energy infrastructure capable of meeting the demands of both traditional industries and the emerging AI-driven digital economy.

## Trends in electricity production

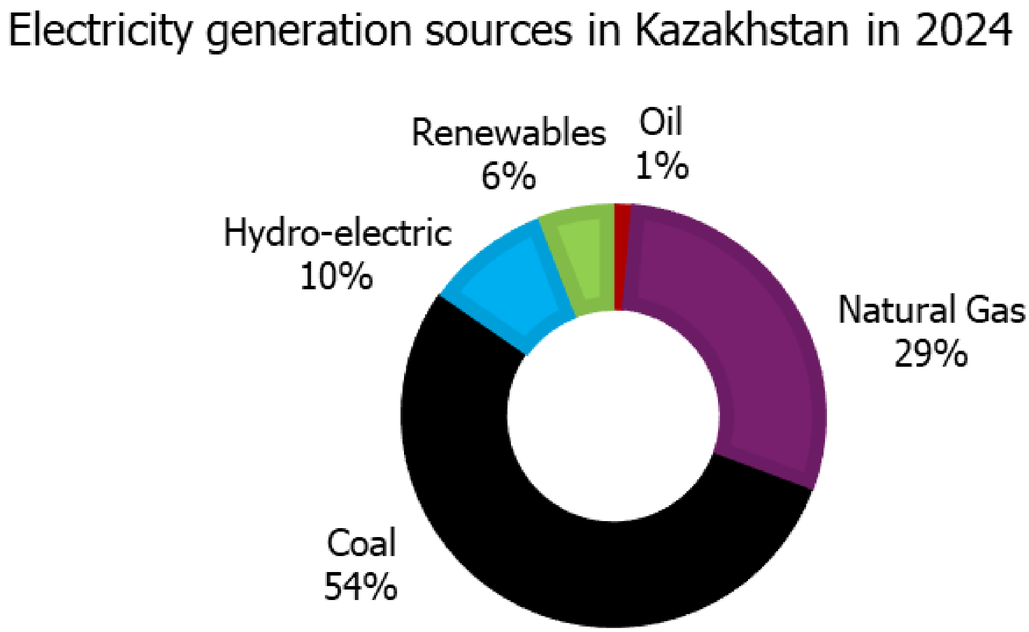
According to the 2025 Statistical Review of World Energy by Energy Institute, the global electricity production rose 4% in 2024, hitting an all-time high of 31,256 terawatt-hours [TWh]. Over the past ten years, worldwide electricity generation has expanded at an average annual rate of 2.6%, which is twice as fast as the 1.3% yearly growth in overall energy demand during the same timeframe. This demonstrates the rapid electrification occurring across the world's energy infrastructure.




Source: Energy Institute, 2025 Statistical Review of World Energy [June 2025]

The chart above shows the breakdown of global electricity generation sources in 2024. The figure illustrates that while fossil fuels still dominate electricity generation (particularly coal), “clean” energy sources have reached 40%, demonstrating substantial progress in decarbonizing the global power sector. The combination of established technologies (hydro and nuclear) with rapidly growing renewables is driving this trend. Total fossil fuels represent approximately 59%, whereas total “clean” energy is approximately 40%.

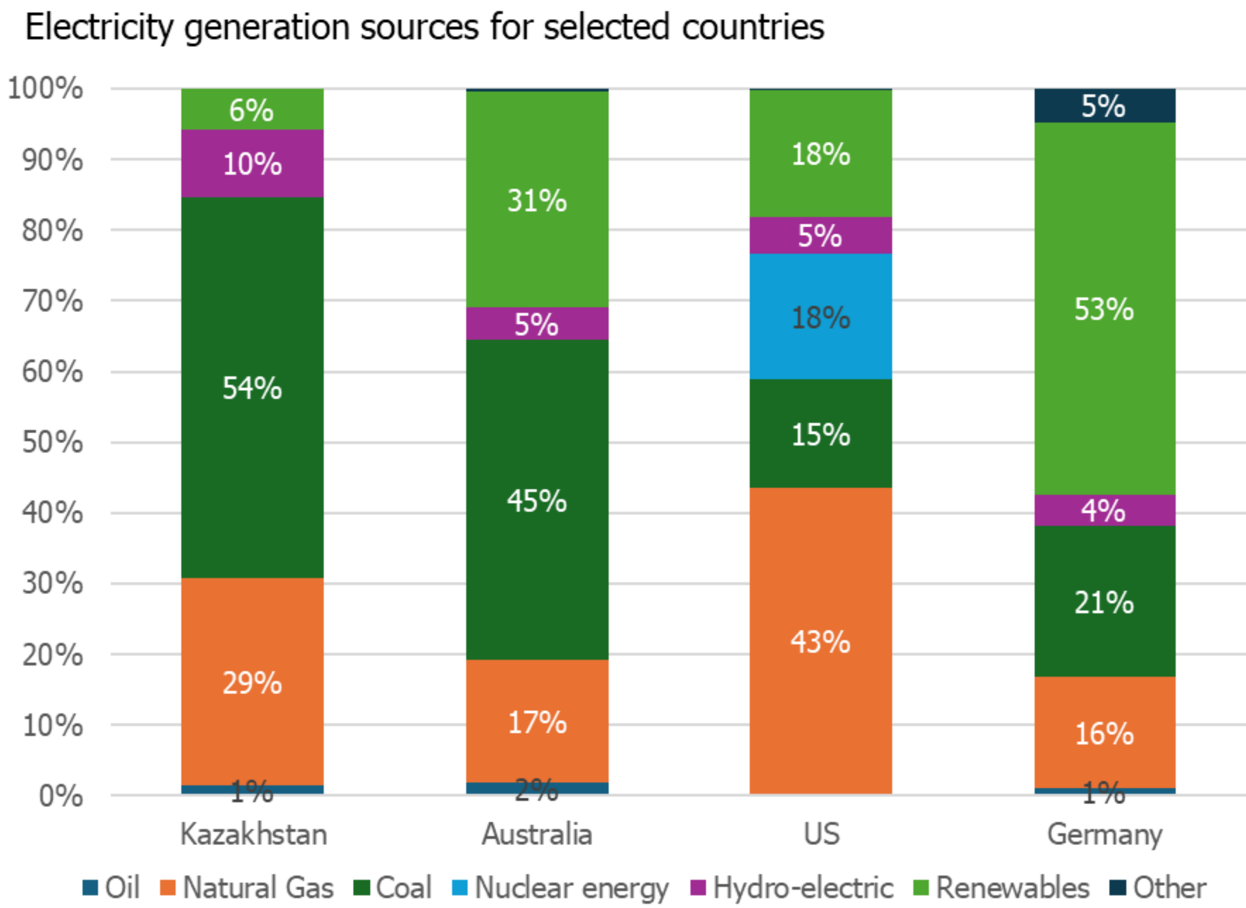
Electricity generation from nearly all energy sources grew worldwide in 2024, with oil being the sole exception. Among fossil fuels, natural gas experienced the largest gain with 2.5% growth, while coal expanded by 1.2% to reach 10,613 TWh, maintaining its position as the dominant generation source. Renewable energy (excluding hydropower) surged by 14%, representing 17% of total electricity production. Solar installation capacity jumped by 32% in 2024, while wind capacity grew by 11%. Additionally, worldwide biofuel production expanded by more than 8%.




Source: based on data from the 2025 Statistical Review of World Energy

This chart illustrates the composition of electricity generation sources in Kazakhstan for 2024, where fossil fuels total 84% (87% in 2023), indicating a carbon-intensive energy system. Kazakhstan's electricity generation is still heavily dependent on coal, which accounts for over half of total production, making it the backbone of the country's electric power sector. "Clean" energy sources (hydro + renewables) contribute only 16% (13% in 2023) of total generation. Natural gas plays a substantial role in nearly one-third of generation. Such a generation structure is typical of a resource-rich country with abundant fossil fuels and deep expertise in the production of hydrocarbons.

Kazakhstan's energy transformation potential becomes clearer through comparison with three countries representing distinct pathways: the United States, with its diversified energy portfolio in the world's largest economy; Australia, sharing similar geographic scale and coal-dependent heritage; and Germany, a frontrunner in renewable energy adoption.




Source: based on data from the 2025 Statistical Review of World Energy

The bar-chart shows that the United States electricity generation dominates ин natural gas (43%) with a strong position in nuclear energy and renewables (approximately 18% of electricity production each). The U.S. electricity generation is less dependent on coal (15%) in comparison with other countries in the benchmark. Germany, on the other hand, leads in renewable sources of electricity production (53% is the highest among the four countries). However, the country is still heavily relying on coal (21%) and has a notable share of electricity from natural gas (16%). Australia is like Kazakhstan in terms of historical coal dependence (45% vs. 54% in Kazakhstan). However, the country shows results of successful rapid renewable energy adoption, with almost 31% of electricity in 2024 being generated from renewable sources. Electricity generation in Australia from natural gas (17%) is still moderate and is similar to Germany (16%).

This chapter showed how different countries source electricity. Kazakhstan still uses a lot of fossil fuels, while others like Germany use more renewable energy. But simply making more electricity, especially "clean" energy, is hard without the right technology. The next chapter will explore the specific technological solutions and infrastructure strategies these countries are using to build more flexible, resilient, and interconnected power systems.

# Energy technology standpoint

The foundation of strong electricity infrastructures of the three countries we use for benchmarking rests on the ability of the electricity grid to accommodate variable renewable generation while maintaining reliability and affordability. This is where the concept of flexible capacity becomes vital, and it is here that Germany's experience offers particularly relevant lessons. Germany has pioneered the implementation of flexible capacity solutions not as an afterthought to renewable deployment, but as an integral component of its energy strategy. The country's approach to flexible time-of-use electricity tariffs and industrial demand response programs demonstrates how grid flexibility can be achieved through market mechanisms rather than solely through infrastructure investment.

The German model gains additional relevance when considered alongside the U.S. Grid Resilience and Innovation Partnerships [GRIP] program. According to Deloitte, the US electricity demand began accelerating in 2025, with peak demand projected to grow by approximately 26% by 2035. The US is addressing this through multiple strategies: the GRIP program received $ 3.9 billion in funding for grid modernization, including smart grid updates, adaptive networked microgrids, and battery storage. This substantial investment reflects a crucial understanding that emerged from multiple grid failures and near-misses across the US: infrastructure resilience cannot be assumed but must be deliberately engineered and continuously upgraded. For Kazakhstan, with its extreme continental climate ranging from minus 40 degrees Celsius in winter to plus 40 degrees in summer, this lesson carries particular weight. The Texas grid failures of 2021, when extreme cold caused widespread blackouts, demonstrated that even wealthy, technologically advanced regions remain vulnerable when infrastructure is not designed for climate extremes.

A series of events in April 2025, which resulted in blackouts across Spain and Portugal, further underscores these vulnerabilities. On April 28th, the situation unfolded with significant voltage fluctuations. Units responsible for voltage control paradoxically generated reactive power, contrary to their intended function. This led to the disconnection of generation facilities, with some power plants shutting down prematurely. Ultimately, this culminated in a loss of synchronization with France, triggering an interconnection trip and a cascading effect of unstable voltage and automatic power plant shutdowns. This incident highlights the critical need for increased energy storage, enhanced interconnections with neighboring countries, and greater demand flexibility within the power grid.

Australia's Rewiring the Nation Fund committed AUD 20 billion ($13.6 billion) to comprehensive grid upgrades. What distinguishes the Australian model is not merely the scale of investment but the strategic recognition that grid infrastructure must be proactively expanded ahead of renewable deployment, rather than reactively upgraded after bottlenecks emerge. This forward-looking approach has enabled Australia to successfully integrate some of the world's highest shares of variable renewable generation (31% based on the chart above) while maintaining grid stability.

The Australian experience directly addresses one of Kazakhstan's most pressing challenges: the country's vast territory, spanning 2.7 million square kilometers as the ninth-largest nation globally, creates enormous transmission distances between potential renewable generation sites and demand centers. Without substantial investment in transmission infrastructure, Kazakhstan's exceptional solar resources in the south and wind resources in the north and west will remain stranded assets, unable to contribute to the national energy mix.

The question of how to finance such substantial infrastructure investment naturally follows from this analysis, and here the international experience suggests that Kazakhstan should fundamentally reframe grid modernization not as a cost but as an enabling investment that unlocks broader economic benefits. Global investment in power grids totaled $390 billion in 2024, which includes investment in transmission and distribution lines, substation equipment, and the digitalization of the grid. These figures reflect a growing international consensus that grid infrastructure investment must accelerate dramatically to catch up with demand growth. For Kazakhstan, the government continues to actively build up its investment potential in the energy sector with 62 projects totaling 72 trillion tenge already formed on the National Digital Investment Platform. Of these, 16 projects worth over 4 billion tenge were launched in 2024. However, given the International Energy Agency's recommendation that grid investment globally must double by 2030, and Kazakhstan's ambitious renewable energy targets requiring electricity demand to rise by close to 60% in the next decade, these investment levels may need to be substantially accelerated to avoid grid bottlenecks.

Energy from renewable sources should be effectively stored and dispatched to meet demand patterns that do not align with generation patterns. The US has seen explosive growth in battery storage deployment, with utilities procuring systems offering 8-to-10-hour duration to provide both peak capacity and renewable firming services. This storage deployment has been driven by rapidly falling costs, with battery prices declining by more than 80% over the past decade, making storage economically competitive with traditional peaking power plants in many markets.

According to Energy Storage Outlook by Rystad Energy, global installed energy storage capacity is projected to increase eightfold, from just under 0.5 terawatt [TW] in 2024 to over 4 TW by 2040. This growth is primarily driven by Battery Energy Storage Systems [BESS]. Aforementioned decline in battery prices combined with extended system lifespans (over 10,000 cycles and 80% battery health guaranteed), this makes electricity storage more affordable and competitive, which is essential for integrating the rising share of intermittent renewable energy into the global power mix, ensuring grid stability, and facilitating the structural decline of fossil fuels in the power sector.

For Kazakhstan, the storage opportunity extends beyond batteries to include pumped hydro storage, leveraging the country's mountainous terrain in the south and southeast. Germany's extensive use of pumped hydro storage, which provides both daily cycling and seasonal storage capabilities, offers a proven model for how geographic features can be converted into grid assets.

Yet storage and flexible capacity, while necessary, are not sufficient without the advanced grid management technologies that enable their effective coordination. Australia has emerged as a global leader in implementing dynamic operating envelopes, which establish time-varying import and export limits for distributed energy resources based on real-time grid conditions, allowing for more intelligent use of hosting capacity. This sophisticated method enables better integration of distributed generation, battery storage, and EV charging loads while maximizing distribution system utilization. This approach represents a fundamental shift from static connection agreements to dynamic grid management, allowing far higher penetrations of distributed generation without costly infrastructure upgrades. The Australian model has particular relevance for Kazakhstan's remote and rural areas, where extending transmission infrastructure to every settlement is economically prohibitive. By enabling microgrids and distributed generation to operate with sophisticated coordination rather than in isolation, dynamic operating envelopes can dramatically improve energy access while reducing infrastructure costs.

The US has similarly embraced flexible interconnection approaches that allow renewable projects to connect to the grid more quickly by accepting curtailment during constrained periods, rather than waiting years for transmission upgrades. This policy innovation addresses one of the most significant barriers to renewable deployment: the interconnection queue. In the US, projects currently wait an average of five years from application to interconnection, with many projects ultimately withdrawing due to cost increases or changed market conditions during this extended timeline. Kazakhstan, in developing its renewable sector, has the opportunity to avoid this bottleneck entirely by implementing flexible interconnection policies from the outset, allowing projects to connect quickly while managing grid constraints through sophisticated control systems rather than through infrastructure alone.

These technological and policy innovations in grid management gain their full potential only when embedded within broader regional interconnection strategies. The US operates multiple major interconnections, including the Western Interconnection, Eastern Interconnection, Quebec Interconnection, and Texas Interconnection, allowing for regional power exchange and improved reliability. Germany's participation in the Continental Europe synchronous grid [ENTSO-E], one of the world's largest interconnected grids, which encompasses 667 gigawatts [GW] of capacity across multiple nations, demonstrates how interconnection enables both reliability improvements and economic efficiency gains through cross-border electricity trade. By the beginning of 2025, 14 European countries had exceeded the 2030 interconnection target of 15%, recognizing that isolated national grids cannot achieve the same level of reliability and economic efficiency as interconnected regional systems. For Kazakhstan, this lesson points toward the critical importance of strengthening the Central Asian Power System, which historically connected the Soviet republics but has atrophied since independence. By leading efforts to modernize and expand interconnections with Kyrgyzstan, Uzbekistan, Tajikistan, and Turkmenistan, Kazakhstan can create a regional market that improves reliability for all participants while enabling electricity trade that captures the economic value of the region's diverse renewable resources.

The interconnection opportunity extends beyond Central Asia to include Kazakhstan's neighbors to the north and east. Enhanced connections with Russia and China could enable Kazakhstan to export renewable electricity during high-generation periods while importing power during periods of domestic shortage. This bidirectional trade capability becomes increasingly valuable as renewable penetration increases, because the variability of wind and solar generation creates periods of both surplus and deficit that can be balanced through regional trade more cost-effectively than through domestic storage alone.

The trend towards restoring a unified energy ring connecting Russia and Central Asian countries is gaining significant momentum, driven by a complex interplay of energy needs, geopolitical shifts, and mutual benefits. This initiative, often described as a revival of a "well-forgotten old" system from the Soviet era, is seen as a pragmatic solution to the pressing energy challenges faced by Central Asian states and a strategic move by Russia to solidify its influence and economic partnerships in the Eurasian space. The proposed energy ring promises substantial economic advantages for all participants. Central Asian countries stand to gain a stable and reliable electricity supply, much-needed investments for modernizing their energy infrastructure, and opportunities for scientific and technical collaboration. Russia, in turn, secures access to a growing energy market in Central Asia, boosts its domestic energy equipment production, and acquires additional mechanisms for stabilizing its own vast energy system. Furthermore, the integration is expected to optimize the utilization of Central Asia's immense, yet underutilized, hydropower resources, thereby reducing the region's reliance on more carbon-intensive fossil fuels and contributing to improved environmental conditions. A unified energy system is also viewed as a powerful tool to enhance energy security and improve grid stability across the region. While challenges related to financing, technical coordination, and political agreements persist, the strong political will and the clear mutual advantages for all participating countries indicate that this trend towards a unified energy ring is set to continue and deepen in the coming years. Russia's full membership in the Coordinating Electric Power Council of Central Asian countries is considered a crucial step towards realizing this transformative project.

Countries with strong interconnections achieve higher renewable penetrations at lower cost than isolated systems, because the geographic diversity of renewable resources across a large area reduces overall system variability. However, interconnection and technological sophistication cannot succeed without the regulatory and policy frameworks that provide investors with confidence and guide market development toward public interest outcomes.

# Kazakhstan’s strategic response

Recognizing the critical importance of energy infrastructure modernization, Kazakhstan has developed a comprehensive strategic response anchored in the Ministry of Energy's long-term forecasts and a multi-pronged approach to capacity expansion. The country's energy strategy addresses both immediate deficits and long-term transformation goals through nuclear power development, renewable energy acceleration, and conventional capacity modernization.

**Forecast balance of electric energy in the unified electric power system of the Republic of Kazakhstan for the period from 2025 to 2031**

**TWh (billion kWh)**

| # | Item | forecast | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | **2025** | **2026** | **2027** | **2028** | **2029** | **2030** | **2031** |
| 1. | Electricity consumption | 122.8 | 127.7 | 133.0 | 138.9 | 144.9 | 151.2 | 157.5 |
| 2. | Electricity production | 117.1 | 125.2 | 134.2 | 142.1 | 149.9 | 150.6 | 150.6 |
| 3. | Existing stations | 116.1 | 113.6 | 113.4 | 112.6 | 113.0 | 113.0 | 113.0 |
| 4. | Planned stations | 1.0 | 11.5 | 20.8 | 29.5 | 36.9 | 37.6 | 37.6 |
| 5. | including renewable energy sources | 7.7 | 9.2 | 10.5 | 10.5 | 16.9 | 16.9 | 16.9 |
| 6. | **Deficit (+), excess (-)** | **5.7** | **2.6** | **-1.1** | **-3.2** | **-5.0** | **0.5** | **6.9** |

Source: Ministry of Energy of the Republic of Kazakhstan, adapted from Russian

According to forecast balances presented in a report on the readiness of the National Electric Grid facilities for the autumn-winter period of 2025-2026 by KEGOC, with an expected maximum load of 17.6 GW and available generation of 16.7 GW, the deficit of 0.9 GW in capacity and 1.1 billion kWh in electricity is projected. It will be covered by imports from neighboring power systems, enabling the country to pass the winter without restrictions.

Kazakhstan's Minister of Energy, Yerlan Akkenzhenov, announced plans to construct three new combined heat and power plants [CHPPs] based on "clean coal technologies" in Kokshetau, Semey, and Ust-Kamenogorsk. This indicates a continued reliance on coal as a significant energy source, albeit with an emphasis on environmental mitigation. By 2029, the Ministry of Energy aims to commission 68 projects with a total capacity of 6.7 GW. This is expected to cover the entire electricity demand of the economy and create a surplus in Kazakhstan's energy system, thereby increasing the country's export potential.  The scale of these projects and the broader context of regional energy integration suggest potential for international (Russia and/or China) collaboration in technology, investment, or construction.

Nuclear energy represents a cornerstone of Kazakhstan's strategic response. Following a national referendum in October 2024, where over 71% of voters supported nuclear power plant [NPP] construction, the country has moved forward with concrete plans. In August 2025, Kazakhstan officially broke ground on its first modern nuclear power plant, launching engineering surveys in Ulken, Almaty region. The exploration work involves drilling at least 50 wells, 30-120 meters deep, with studies lasting 18 months to guide the final decision on the plant's exact location. The facility will use Russia's VVER-1200 reactor design, a Generation 3+ pressurized water reactor with a 60-year lifespan that can be extended for another two decades.

In October 2025, Almasadam Satkaliyev, head of Kazakhstan's Agency for Atomic Energy, announced plans to construct a second NPP in the Zhambyl district of the Almaty region. The primary motivation for locating both NPPs in the south is the region's energy deficit, which currently relies on electricity transmitted from the north. These new plants are expected to ensure a reliable and stable energy supply to the southern regions. While not finalized, the Chinese company CNNC is being considered a priority partner for the NPP projects. By 2035, Kazakhstan aims to have 2.4 GW of nuclear power capacity.

In contrast with other initiatives in clean energy's capacity expansion, storage systems remain a critical challenge. As Nurlan Kapenov, Qazaq Green board chairman, noted, ensuring reliability and consistency of power supply is a major challenge in integrating renewable energy sources into power systems. The basic technological principle of sustainable energy system operation requires preserving the balance between generation and constantly changing consumption. To address this challenge, Kazakhstan held its first auctions in April 2025 for large wind power projects that include storage systems. During COP29, a Power Purchase Agreement was signed with Masdar (UAE) for the construction of a 1-gigawatt wind farm with 300-megawatt energy storage systems at two-hour capacity. Additional agreements were signed with Total Energies (France) for a similar 1-gigawatt wind power plant paired with a 300-megawatt, two-hour BESS.

Kazakhstan's strategic response also includes comprehensive grid infrastructure modernization. The company KEGOC, which operates the national electric grid, announced planned repairs in 2025 at 577 facilities with a total cost of 3.8 billion tenge. Moreover, in 2025, KEGOC is implementing an investment programme of 99 billion tenge, of which 23.1 billion tenge is allocated to sustaining current production levels by increasing capacity and power of autotransformers. In parallel, KEGOC is implementing major infrastructure projects, including the South Kazakhstan Electricity Transmission Reinforcement Project, which will increase the North–South transit capacity by 440 megawatts [MW] and enable the integration of new generation sources, including renewables, and West Kazakhstan Electricity Transmission Interconnection Project, aimed at improving the resilience of electricity supply and fostering the development of renewable energy. From a strategic perspective, up to 2035, the company plans to implement system-forming projects: construction of approximately 7,000 kilometers of transmission lines, introduction of digital substations, and expansion of the North–South transmission capacity to 2,000 MW. These initiatives will create a robust technological foundation for the further development of Kazakhstan's energy sector.

# The Bottom Line

The comparative analysis with the United States, Australia, and Germany demonstrates that Kazakhstan has considerable ground to cover in its energy system development. These countries have successfully developed diverse energy systems with substantial renewable energy capacity, advanced energy storage solutions, and flexible grid infrastructure. In contrast, Kazakhstan is currently navigating a complex transition, balancing its historical reliance on coal with ambitious plans for modernization and diversification. While the country continues to operate a significant number of coal-fired power plants, many of which are aging with an average equipment wear level of 56%, there's a clear strategic push to upgrade and expand its generation capabilities. This includes not only the construction of three new CHPPs with incorporated "clean coal technologies", but also projects like the restoration of power unit No. 1 at GRES-1 and the reconstruction of GRES-2 in Ekibastuz.

Kazakhstan has developed a comprehensive strategic response to these challenges. The strategy combines several key elements: nuclear power development to provide stable baseload capacity, ambitious renewable energy expansion, and major grid infrastructure projects. This balanced approach addresses both immediate capacity shortages and long-term sustainability requirements. The outcome of this transformation will determine whether Kazakhstan can achieve its economic objectives while ensuring its strategic positioning in the AI era. The country should compete in an increasingly electrified global economy where energy infrastructure quality directly impacts competitiveness.

# ENERGY Insights & Analytics

Analytical center "ENERGY" LLP (ENERGY Insight & Analytics) is a joint venture between the KAZENERGY Association and the IT company AppStream. The company aims to become a priority source of data, analytical information, and recommendations for Kazakhstan's oil, gas, and electric power industries, allowing decision-makers to analyze and predict the most significant industry indicators with details on leading market players. Activities of ENERGY Insight & Analytics incorporate the whole analytics cycle with consequent stages: Descriptive, Diagnostic, Predictive, and Prescriptive analytics.

The key tool and product of ENERGY Insight & Analytics is internally developed software - the Analytical Platform EXia, aimed to identify, localize, format, and present data most efficiently for the specified use cases.

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