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Integrated Policy Strategies and Regional Policy Coordination for Resilient, Green and Transformative Development: Supporting Selected Asian BRI Partner Countries to Achieve 2030 Sustainable Development Agenda

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Energy sector for green transitioning

Abstract

The report is structured in next parts such as executive summary, introduction and six sections. Executive summary provides shortly the main theses of the report and introduction gives the background to the report and short overview of the questions raised in the report. Chapter 1 provides a global situation with green energy and the perspectives in the future according to international organizations visions. Chapter 2 gives the snapshot of the energy sector of Kazakhstan with focus on GHG and economic profiles and overview of power sector as main sector for green transition. Chapter 3 looks and discusses the progress of renewables and alternative sources of energy and their challenges and opportunities to clean the whole power sector. Chapter 4 investigate the scenario of clean energy sources where the comparison is done between them on cost considerations. Chapter 5 and 6 presents policy considerations and strategic recommendations for the energy sector greening and concluding remarks on the work done.

Contents

KEYWORDS: Green Transition, Energy, Nuclear, Renewables

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EXECUTIVE SUMMARY

As global climate change impacts intensify, the urgency for sustainable energy solutions has escalated, prompting nations worldwide to pursue ambitious climate targets. This work delves into Kazakhstan’s energy sector, emphasizing the critical role of green transitioning from fossil fuels to low-carbon energy sources.

Kazakhstan has made notable strides in its commitment to sustainable development and renewable energy. The "Green Economy Concept" sets a target of generating 15% of electricity from renewables by 2030, marking a shift toward a sustainable economic model. By ratifying the Paris Agreement, the country pledged to cut greenhouse gas emissions by 15% by 2030 compared to 1990 levels. In 2023, Kazakhstan adopted its Strategy for Achieving Carbon Neutrality by 2060.

The global energy sector is transitioning to cleaner solutions to address climate change and rising demands. The Intergovernmental Panel on Climate Change (IPCC) highlights electricity production, transport, and industry as key contributors to emissions. The International energy agency (IEA) reports a 2.2% rise in electricity demand in 2023, with 3.4% annual growth expected through 2026, driven by electrification and economic expansion.

The goal of tripling renewable power capacity to 11.2 TW by 2030, supported by 133 countries under the United Arabic Emirates Consensus, requires an annual addition of 1,044 GW, according to IRENA’s 1.5°C Scenario. Despite a record 473 GW added in 2023, significant gaps remain, with solar and wind capacity growth falling short of targets. Current national plans are projected to achieve only 48% of the required increase, leaving capacity 34% below the goal.

In 2022, nuclear power supplied 9.2% of global electricity and 20% in advanced economies, producing 2545 TWh with 411 reactors and a capacity of 371 GW. Nuclear energy is vital for low-carbon electricity, avoiding over one billion tonnes of CO2 annually, and supporting energy security and reliability. The International Atomic Energy Agency (IAEA) projects nuclear capacity to grow 22% by 2030 and potentially double by 2050.

Kazakhstan's energy sector remains a cornerstone of its economy, heavily dependent on fossil fuels, alongside substantial reserves of uranium and potential in solar and wind energy. The energy infrastructure, rooted in the Soviet era, reflects a legacy of investment in fossil fuel extraction and processing, which continues to shape the country's energy policies and economic strategies. In 2023, primary energy production totaled 162.9 million tonnes of oil equivalent, with 99.2% derived from fossil fuels and only 0.8% from renewables, while 55% of this energy was exported.

Domestically, total primary energy consumption reached 73.4 million tonnes of oil equivalent in 2023, dominated by fossil fuels (98%), with coal contributing 49.6%, followed by natural gas and oil products. Final energy consumption rose to 43.4 million tonnes of oil equivalent, primarily driven by industry, transport, and buildings, with fossil fuels leading and renewables playing a minor role. Oil continues to play a vital role in Kazakhstan's economy, accounting for significant exports and supporting GDP growth, with 89.9 million tonnes of crude oil produced in 2023, of which 78.4% was exported.

Kazakhstan's GHG emissions have mirrored the economy's trajectory since 1990, initially declining in the 1990s, then recovering with economic growth in the 2000s, with notable slowdowns during the 2008 and 2015 global crises. Emissions peaked in 2018 at 404.5 million tonnes CO2-equivalent, surpassing the 1990 level by 6.4%, but declined in 2019–2021 due to the impacts of COVID-19. The energy sector is the

primary source of GHG emissions in Kazakhstan, contributing 261.9 million tonnes CO2-equivalent or 76.9% of the nation's total 340.8 million tonnes in 2021.

Kazakhstan’s power sector oversees energy reliability, accessibility, and sustainability. As of early 2024, the country operates 222 power plants with an installed capacity of 24,641.9 MW and available capacity of 20,428.4 MW. In 2023, electricity consumption rose by 1.8% to 115 billion kWh, while production remained steady at 112.8 billion kWh, highlighting the need for expanded capacity to meet rising demand.

In 2023, Kazakhstan's GDP reached 120.56 trillion tenge ($264.21 billion), reflecting a 5.1% real growth. The electricity, heat, and air conditioning sector contributed 1.3% to GDP, amounting to 1.6 trillion tenge ($3.51 billion), with a 1.8% increase in real output compared to 2022. The sector’s average salary rose by 22.9% nominally and 7.3% in real terms, outpacing the national average despite being 9.4% lower overall. Employment in the sector stood at 148.9 thousand people, representing 1.64% of total national employment.

In 2023, renewable energy facilities in Kazakhstan generated 6,675 million kWh, accounting for 5.92% of the country's total electricity production—exceeding the planned target of 5% by 18.4%. The breakdown includes 3,825 million kWh from wind power plants, 1,854 million kWh from solar power plants, 994 million kWh from hydroelectric power plants, and 2.71 million kWh from bioenergy plants. This progress highlights the active growth and integration of renewables into Kazakhstan's energy system. By the end of 2023, 144 renewable energy facilities with a total installed capacity of 2,868.6 MW were operational across the country.

Kazakhstan holds 12% of the world's uranium resources and produced 21,112 tonnes of uranium in 2023, maintaining its position as the world’s leading uranium producer, accounting for 40% of global output. With over 700,000 tU in explored reserves, the country ranks second globally in proven uranium reserves. In addition to mining, Kazakhstan has expanded its role in the nuclear fuel cycle, including access to uranium enrichment services, manufacturing uranium oxide powder, and producing uranium dioxide fuel pellets. The nation opened a nuclear fuel assembly plant at the JSC Ulba Metallurgical Plant in 2021 to further enhance value addition. The national atomic company Kazatomprom, established in 1997, oversees all nuclear-related activities and controls uranium exploration, mining, and trade.

The debate over nuclear power in Kazakhstan reflects the global tension between leveraging its low-carbon benefits and addressing significant challenges. The country faces hurdles like high initial costs, long timelines, public opposition due to historical safety concerns, and waste management issues. However, nuclear energy offers critical opportunities for diversifying Kazakhstan's energy mix, enhancing energy security, and achieving carbon neutrality by 2060. With substantial uranium resources and expertise, Kazakhstan is well-positioned to integrate nuclear power into its energy strategy.

Nuclear power can significantly contribute to Kazakhstan’s green industrialization by reducing emissions, creating high-skilled jobs, and promoting technological innovation, reinforcing the country’s energy transition goals.

The analysis of the costs of various renewable and alternative energy sources for Kazakhstan highlights factors influencing construction expenses, such as technology, labor, experience, economies of scale, and licensing. Globally, the overnight costs of constructing nuclear power plants range widely, from $2,157 per kW in South Korea to $6,920 per kW in Slovakia, with an average CAPEX of $3,606 million per GW. For Kazakhstan, estimates for a 2.4 GW NPP range from $4,167 to $6,250 per kW, reflecting high uncertainty.

A key cost metric, the capacity factor, shows nuclear power plants outperforming renewables significantly, with global averages of 79% for nuclear compared to 59% for hydro, 24% for wind, and 16% for solar. This means more capacity must be installed for renewables to match nuclear output, increasing their overall costs. For example, generating the same electricity as a 1 GW nuclear plant requires 1.3 GW of hydro, 3.4 GW of wind, or 4.9 GW of solar. While wind and solar have lower initial CAPEX per kW, adjusting for capacity factors aligns their total costs ($4,000–$5,000 million per GW) with those of nuclear ($4,250 million). These insights underline the need for comprehensive cost comparisons, factoring in efficiency, reliability, and operational lifespan, when evaluating Kazakhstan's energy investment options.

The elaborated recommendations during the analysis aim to provide a comprehensive roadmap for transforming Kazakhstan’s power sector, fostering sustainability, and meeting decarbonization goals by leveraging innovative technologies, regulatory reforms, and targeted Reformation the system of setting tariffs in the power sectors with inclusion of emission reduction costs, redirecting fossil fuel subsidies to targeted subsidies for vulnerable populations, and incentivize efficiency.

- Development a master plan for energy system development with decarbonization goals, integrating renewable energy deployment and modernization needs;
- Improvement renewable energy forecasting, reinstate differentiated time-of-use tariffs, and encourage energy-saving behaviors;
- Development a phase-out plan for decommissioning coal facilities with defined timelines, required investments, and owner compensation mechanisms;
- Consideration of constructing gas-fired combined cycle plants for balancing the energy system and increasing gas resource accessibility for flexible power generation;
- Development of a roadmap for transitioning coal-based combined heat and power plants to gas fuel;
- Development of strategies for renewable energy growth, addressing siting, energy storage, and network alignment;
- Launching pilot projects for energy storage systems to address renewable intermittency and daily load balancing;
- Formulation long-term strategy for nuclear energy, including small modular reactors, to supplement the energy mix;
- Implementation demand-side management programs and advanced digital technologies for optimizing energy use and reducing transmission losses;
- Building of national research and engineering expertise to support energy transition efforts and adjust strategies in line with global trends.

By following these recommendations, Kazakhstan can effectively develop a sustainable and efficient green energy sector, strengthening its energy security, supporting economic growth, and contributing to global efforts in reducing carbon emissions. This strategic approach will position Kazakhstan as a leader in green energy innovation within the Central Asia region.

Introduction

As the impacts of climate change continue to unfold globally, the urgency for sustainable and environmentally-friendly energy solutions has never been greater. Green transitioning is essential to mitigate climate change, reduce greenhouse gas emissions, and ensure a sustainable future.

The global world is undergoing a significant energy transformation. Nations worldwide are committing to ambitious climate targets, such as the Paris Agreement's goal to limit global warming below 2 degrees Celsius above pre-industrial levels. This commitment has catalyzed the adoption of alternative and renewable energy sources, as well as innovative technologies aimed at improving energy efficiency and reducing carbon footprints.

However, the transition to a green economy is fraught with challenges. Renewable energy sources, while abundant and sustainable, often face issues related to intermittency, storage, and high initial costs. Additionally, the existing energy infrastructure, heavily reliant on fossil fuels, poses substantial barriers to rapid and effective change.

Kazakhstan, the largest landlocked country in the world and a key player in the global energy market, finds itself at a crossroads. Rich in fossil fuel resources, Kazakhstan has traditionally relied on coal, oil, and natural gas for its energy needs, contributing significantly to its gross domestic product (GDP), exports, and employment. However, this reliance comes at a substantial environmental cost, with the energy sector being a major contributor to the country's greenhouse gas emissions (GHG).

Kazakhstan has demonstrated a growing commitment to sustainable development and green energy through several key initiatives and policies. The country has set ambitious targets to generate 15% of its electricity from renewable sources by 2030 in the "Green Economy Concept" to transition to a sustainable economic model (Green Concept RK. 2013). By ratifying the Paris Agreement in 2016, Kazakhstan committed to reducing unconditionally its greenhouse gas emissions by 15% by 2030 compared to 1990 levels in its national determined contribution (NDC) (NDC RK, 2023). In its NDCs, Kazakhstan provides actions to increase renewable energy capacity, enhance energy efficiency, and implement carbon pricing. Significant investments have been made in renewable energy projects, supported by favorable policies and incentives. Additionally, various programs to improve energy efficiency across sectors and strengthened environmental legislation underscore Kazakhstan's dedication to aligning economic growth with environmental protection.

In 2023, Kazakhstan approved its Strategy of achieving the carbon neutrality of Kazakhstan by 2060 (LEDS RK, 2023), in which the country outlines conceptual vision and comprehensive measures to transition to a low-carbon economy. This strategy includes significant investments in renewable energy, advancements in energy efficiency, and the integration of innovative technologies to reduce greenhouse gas emissions, while promoting sustainable industrial practices and enhancing environmental protection. The Strategy outlines the necessity of the alternative energy sources such as nuclear sector development and hydrogen technologies introduction.

By integrating alternative green power into its energy portfolio, Kazakhstan can diversify its energy sources, reduce its dependence on fossil fuels, and make significant advancement towards achieving its climate goals. This strategic move can also position Kazakhstan as a leader in the Central Asia region, showcasing a balanced approach to energy development that harmonizes economic growth with environmental sustainability.

The report will discuss the following key aspects:

- Overview of global energy system with focus on power sector and the roles of renewables and nuclear in its path to decarbonization goals;
- Overview of energy sector profile of Kazakhstan, including contributions to GHG emissions, to GDP, to exports, and other factors of influence;
- Discuss the key challenges and opportunities on developing and using solar, hydro, wind and nuclear power with a particular focus on industrialization;
- Discuss past and present policies and strategies, past initiatives to switch to alternative energy systems, with a critical eye and highlight major concerns, failures and successes, opportunities and the most significant challenges preventing certain alternative power sources, such as the nuclear to become the key energy source in green industrialization;
- Discuss comparable examples from different countries to compare and contrast initiatives, lessons, on how best to implement green energy as an alternative source;
- Provide a scenarios considering costing and effectiveness of clean sources;
- Make policy recommendations in light of the analysis.

By understanding the role of alternative green energies, in all its different forms, including hydro, solar, wind and nuclear and their challenges and opportunities, Kazakhstan can take steps to settle the optimal power sector. This work aims to be a valuable resource for policymakers, stakeholders, and the general public.

1. Global Energy Sector Perspectives

The global energy sector is undergoing a transformative shift as countries prioritize cleaner, more sustainable energy solutions to address climate change, reduce dependency on fossil fuels, and meet rising energy demands.

According to the Guidelines of Intergovernmental Panel on Climate Change (IPCC), the Energy sector includes such categories as electricity and heat production, refinery plants, industry, construction, transport, buildings, agriculture with forestry and fishing, others. In other words, the Energy sector here represents all activities across economy and populations that related to direct combustion of fossil fuels to get energy and fugitive emissions when mining and extracting of fossil fuels. This representation of the sector will be used throughout the paper.

According to the recent report of International energy agency (IEA) on electricity, the world's demand for electricity grew by 2.2% in 2023, less than the 2.4% growth observed in 2022 (IEA, 2024a).

Global electricity demand is expected to rise at a faster rate over the next three years, growing by an average of 3.4% annually through 2026. The rise is driven by economic perspectives, which will contribute to faster electricity demand growth both in advanced and emerging economies (See table 1 below).

Table 1. Global electricity supply, TWh

	2021	2022	2023	2026
Coal	10284	10442	10613	10088
Natural gas	6556	6609	6639	6785
Other non-renewables	852	857	782	705
Renewables	7925	8549	8959	12158
Nuclear	2809	2668	2741	2959
Total	28426	29125	29734	32695

Sources: IEA Electricity report 2024 (IEA, 2024a)

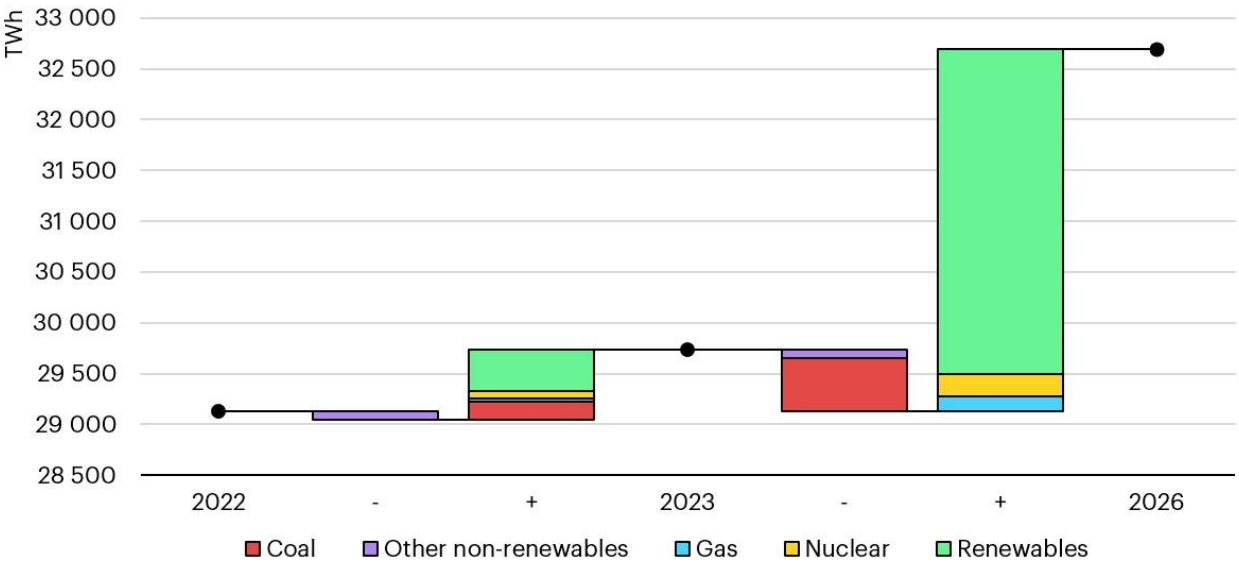
According to report of IEA report (IEA, 2024a), electricity demand in advanced economies and China will be supported by the electrification of the residential and transport sectors, and by an expansion of the data center sector. The share of electricity in final energy consumption is estimated to have reached 20% in 2023, up from 18% in 2015. Notably, the increase of electricity by data centers, artificial intelligence, and the cryptocurrency sector could potentially double by 2026: data centers alone consumption will rise from 460 TWh in 2022 till 1,000 TWh by 2026.

Till 2026 year, about 85% of additional electricity demand comes from emerging and developing countries and China. Chinese electricity demand grows 5.1% in 2024, 4.9% in 2025 and 4.7% in 2026. India's electricity demand is expected to grow annually by rate of 6% until 2026, supported by economic activity and expanding ownership of air conditioners. Africa's total electricity demand is expected to grow by 4% annually from 2024 to 2026 and two-thirds of this increase will be met by renewable energy and other by natural gas. Electricity demand in United States is expected to rise by 2.5% in 2024 and 1% average growth in 2025-26, driven largely by electrification and data center expansion. European Union electricity demand growth is expected rise by an average 2.3% in 2024-26 with support of electric vehicles, heat pumps and data centers are responsible for half of the growth.

1.1 The role of renewables

According to report of IEA on electricity, clean electricity will meet all of the global electricity demand by 2026 (IEA, 2024a). As it can be seen from the figure below, clean energy will substitute the fossil fuel decrease in growth and cover other part of additional increase of demand.

Figure 1. *The structure of electricity growth by types of energy source, TWh*



Sources: IEA Electricity report 2024 (IEA, 2024a)

The share of renewables in global power generation is projected to grow from 30% in 2023 to 37% by 2026, primarily driven by the rapid expansion of increasingly affordable solar PV (IEA, 2024a).

The renewables role in mid-term is highly appreciated by the setting the goal of the tripling of installed renewable power generation capacity by 2030 in the UAE Consensus for keeping the 1.5°C goal and 133 countries supported this goal(COP28 UAE, 2023).

According to IRENA 1.5°C Scenario, achieving the tripling of renewable power capacity should reach 11.2 TW by 2030 and it requires an average annual addition of 1 044 GW in the period of 2024 and 2030 years. The installed capacity should rise with a compound annual growth rate of 16.4% (IRENA, 2024a).

In 2023 year, a record 473 GW of renewable power capacity was added and it is 54% higher than in 2022. However, this rate is much lower of required 1044 GW of annual addition. Even the significant acceleration in solar photovoltaic deployment with annual growth of 346.9 GW in 2023 is lower than required 578 GW of annual capacities to achieve the goal. The wind capacities annual addition in 2023 of 114.5 GW is behind of required 360 GW, and the same with other types of renewable energy (COP28 UAE, 2023).

Existing national plans and targets are projected to achieve only half of the needed annual growth in renewable power capacity. These current plans would provide just 48% (3.5 TW) of the required increase, bringing global installed capacity to 7.4 TW by 2030, which is 34% (3.8 TW) below the goal of tripling capacity. This gap highlights that current policies fall short in limiting global temperature rise to 1.5°C, emphasizing the urgent need for stronger policy (IRENA. 2024b).

The International energy agency (IEA) in the report on renewables in 2024 (IEA, 2024b) states that renewable energy consumption in the power, heat and transport sectors increases near 60% over 2024-2030. This increase boosts the share of renewables in final energy consumption to nearly 20% by 2030, up from 13% in 2023. The next milestones on the renewables will be observed in close future:

- In 2024, solar PV and wind generation together surpass hydropower generation.
- In 2025, renewables-based electricity generation overtakes coal-fired.
- In 2026, wind and solar power generation both surpasses nuclear.
- In 2027, solar PV electricity generation surpasses wind.
- In 2029, solar PV electricity generation surpasses hydropower and becomes largest renewable power source.
- In 2030, wind-based generation surpasses hydropower.

By 2030, renewable energy sources contribute 46% to global electricity generation, with wind and solar PV accounting for 30% collectively. During this period, solar PV emerges as the leading renewable electricity source, overtaking hydropower, with wind following closely behind (IEA, 2024b).

1.1.1 Technological advances and innovations in renewables

Technological advances and innovations are revolutionizing the renewable energy sector, making it more efficient, affordable, and accessible. Tracking the full scope of technological advances in renewable energy is challenging due to the rapid pace of innovation and the substantial investments driving research and development. Despite this vast landscape, several key trends are observed such as next-generation solar and wind technologies, energy storage breakthroughs, hydrogen from renewables, smart grids and artificial intelligence.

Innovations like perovskite solar cells are enhancing efficiency and reducing costs, while floating PV maximizes space by utilizing water surfaces for solar energy generation, ideal for areas with limited land. Emerging technologies such as agri-PV and floating solar present promising clean energy opportunities, despite concerns about high investment costs.

Offshore wind developments, including floating turbines, are extending wind energy's reach into deeper waters where wind speeds are stronger and more consistent, significantly boosting energy generation potential. Floating turbine technology enables the installation of wind farms in areas previously inaccessible to fixed-bottom turbines, opening new frontiers for large-scale renewable energy projects while reducing visual and environmental impacts near coastlines.

Advancements in battery technologies, such as solid-state batteries and grid-scale storage, are crucial for addressing renewable energy intermittency and ensuring stable power supplies. Storage solutions like battery grids, thermal storage, and mechanical systems enable efficient energy use and reduce reliance on fossil fuels, with significant investments like California's Moss Landing Energy Storage Facility with 3 GW of capacity showcasing global commitment to sustainable energy infrastructure.

Digital technologies are revolutionizing grid management, enabling seamless integration of distributed energy resources and boosting overall energy efficiency. The International Energy Agency (IEA) estimates these innovations could save up to USD 1.8 trillion in global grid investments by 2050, enhancing grid lifespan, optimizing renewable energy use, and reducing supply disruptions (IEA, 2023).

A notable innovation is vehicle-to-grid (V2G) technology, enabling electric vehicles (EVs) to supply stored energy back to the power grid during peak demand, addressing short-term grid storage needs on a global scale. Meanwhile, advancements in green hydrogen technologies are proving transformative, offering decarbonization solutions for hard-to-electrify sectors such as transportation and heavy industry.

By leveraging these technologies, countries can accelerate their decarbonization efforts, optimize energy efficiency, and enhance the reliability of renewable energy systems. These trends highlight the transformative potential of ongoing research and underscore the importance of sustained investment in renewable energy innovation.

1.2 The role of nuclear power

According to the International Atomic Energy Agency (IAEA), nuclear power plants in 2022 provided approximately 9.2%, a decrease of 0.6 percentage points from the previous 2021 year of the world's electricity (IAEA, 2023a). This share is about the 20% in advanced economies (IAEA, 2022). In absolute values, the electricity production in 2022 was 2545 TWh. At the end of 2022, 411 nuclear power reactors were operational, with a total net installed power capacity of 371 GW.

The nuclear power is a key economic source of low carbon electricity and heat, helping to avoid more than one billion tonnes of carbon dioxide (CO2) emissions annually while supporting energy system reliability, long term security and climate resilience (IAEA, 2023b).

According to IAEA (IAEA, 2023a), total electrical generating capacity is expected to increase by about 22% by 2030 and then double by 2050 achieving 16590 GW from 8281 GW in 2022. In the high case, nuclear electrical generating capacity is projected to increase by about 24% by 2030 and increase by about 140% by 2050 compared with 2022 capacity. In the low case, nuclear electrical generating capacity is projected to increase by about 9% by 2030 and then increase by about 23% by 2050. The capacities in 2050 are estimated in the range of 458 - 890 GW.

IAEA projected the total electricity production to increase from 27672 TWh in 2022 by about 20% by 2030 and by about 80% by 2050 achieving the level of 50071 TWh. In the high case, nuclear electricity production is expected to increase by about 40% from the 2022 level by 2030 and by almost 3-fold by 2050, from 2575 TWh in 2022 to 7158 TWh in 2050. The share of nuclear in total electricity production is expected to increase by more than 5 percentage points. In the low case, nuclear electricity production is expected to increase by about 24% from the 2022 level by 2030, rising to 53% by 2050, from 2575 TWh in 2022 to 3901 TWh in 2050. The share of nuclear in total electricity production is expected to decline by about one and a half percentage points.

International Atomic Energy Agency claims that urgent actions are needed to maintain the existing role of nuclear power in the energy mix (IAEA, 2023a) and support the sustainable electricity consumption growth, as well as climate change and air quality concerns, the security of energy supply and the price volatility of other fuels. It is necessary the involvement of a broad range of actors including policy makers, the nuclear industry, the financing community and international organizations, along with active engagement with the public.

1.2.1 Technological advances and innovations in nuclear

The latest technological innovations and advancements in nuclear energy can support world efforts to achieve a cleaner, more efficient, and more resilient energy system. By leveraging cutting-edge technologies, the world energy sector has the potential to

enhance energy security, reduce greenhouse gas emissions, and drive economic growth through green industrialization.

The Intergovernmental Panel on Climate Change (IPCC) has emphasized the importance of nuclear energy in scenarios that aim to limit global warming to 1.5 degrees Celsius, citing its potential to reduce greenhouse gas emissions significantly.

Nuclear power can deliver low-carbon energy at scale and it will require improvements in managing construction of reactor designs that hold the promise of lower costs and broader use. Unfortunately, currently, nuclear power continues to be affected by cost overruns, high upfront investment needs, challenges with final disposal of radioactive waste, varying public acceptance and political support levels. The uranium resources have been increasing steadily over the year according to the estimated and it means there are sufficient resources for substantially increasing nuclear deployment. Conventional global uranium resources have been estimated to be sufficient for over 130 years of supply at current levels of use (IPCC SAR, 2022).

There are several possible nuclear technology options for the period from 2030 to 2050. In addition to electricity, nuclear can also be used to produce low-carbon hydrogen and freshwater. The trends in nuclear power technologies are the large reactors with advanced safety, long-term operation (LTO) of the current fleet, and small modular reactors (SMR). New designs of large reactors enhance safety, efficiency, and capacity, offering robust solutions for stable electricity generation. Long-term operation (LTO) extends the life of existing nuclear power plants through rigorous upgrades and maintenance. By maximizing the use of existing infrastructure, LTO provides cost-effective energy while reducing greenhouse gas emissions. Small Modular Reactors (SMRs) are compact and flexible, making them ideal for remote areas or smaller grids. Their modular design enables quicker deployment and integration with renewable sources, offering a scalable solution for low-carbon energy needs.

2. Energy sector in Kazakhstan

According to the Guidelines of Intergovernmental Panel on Climate Change (IPCC), the Energy sector includes such categories as electricity and heat production, refinery plants, industry, construction, transport, buildings, agriculture with forestry and fishing, others. In other words, the Energy sector here represents all activities across economy and populations that related to direct combustion of fossil fuels to get energy and fugitive emissions when mining and extracting of fossil fuels. This representation of the sector will be used throughout the paper.

This chapter provides the status of energy sector in Kazakhstan, its input into the GHG emissions, and the economic contribution of the power and heat sector to the economy.

2.1 Current Energy Sector Profile

Kazakhstan's energy sector is an important element of the economy, which heavily reliant on abundant fossil fuel resources, including oil, gas, and coal, while also possessing significant solar, wind potential and uranium deposits. The Kazakhstan's current energy infrastructure shape is rooted in Soviet time and advanced in independence era.

The Soviet era established a deep dependency on fossil fuels within Kazakhstan's energy sector, which was developed to fuel the broader Soviet industrial complex with oil, gas, and coal resources. This period saw extensive investment in extracting and processing fossil fuels, creating an infrastructure that continues to dominate the country's energy landscape. This legacy has resulted in a significant reliance on fossil

fuels, which has persisted into the present day, shaping Kazakhstan's energy policies and economic strategies.

The energy sector can be analysed by looking at its energy balance as in the table 2 below.

Table 2. National energy balance of 2023, million tonnes of oil equivalent

	Coal	Natural gas	Oil	Hydro	Solar	Wind	Biofuel	Electricity	Heat	Total
Primary energy production	50.4	25.4	85.8	0.8	0.2	0.3	0.039			162.9
Import	0.6	1.1	1.4				0.006	0.4		3.5
Export	-14.2	-6.2	-69.2				-0.008	-0.2		-89.8
Bunkering and changes	-0.4		-2.1				-0.002			-3.2
TPES	36.4	19.6	15.9	0.8	0.2	0.3	0.035	0.2	0.0	73.4
Statistical discrepancies	0.00	-0.76	-0.03							-2.06
Transformation sectors	27.2	11.1	0.1	0.76	0.16	0.3	0.016	-9.8	-9.2	20.6
Own use, losses and others	0.8	2.2	2.4					3.4	2.6	11.4
TFC	8.4	7.1	13.5				0.019	6.5	6.6	43.4
Industry	4.0	1.5	1.4				0.001	3.5	1.3	12.3
Transport	0.0	0.0	8.2					0.3	0.0	8.6
Buildings	4.3	5.6	2.1				0.016	2.5	5.3	19.9
Others	0.1	-0.1	1.7				0.002	0.2	0.1	2.7

Sources: Fuel and energy balance of the Republic of Kazakhstan (BNS RK, 2023a)

In 2023, Kazakhstan had energy resources or primary energy production in the amount of 162.9 million tonnes of oil equivalent which is higher than in 2022 by 1.4% (160.7 million tonnes of oil equivalent). From this volume of energy 45.0% or 73.4 million tonnes of oil equivalent were used domestically and other 55.0% were exported (BNS RK, 2023a).

Of the 162.9 million tonnes of oil equivalent of primary energy production, 99.2% were fossil fuels and their derivatives, and 0.8% was renewable energy resources. The structure of fossil fuel in production part consists of 31.0% of coal, 15.6% of natural gas and 52.7% of crude oil and condensate.

Total primary energy consumption (TPES) in 2023 is 73.4 million tonnes of oil equivalent which is higher than in 2022 with 69.9 million tonnes of oil equivalent. This energy is the energy that consumes domestically for economic purposes and needs of population. The fossil fuel dominates here as well consisting of 98.0% and other 2.0% is renewable energy. The fossil fuel energy consists of 49.6% of coal, 26.7% of natural gas and 21.7% of oil products.

Total final consumption (TFC) consists of direct combustion of fuels in industry, transport, agriculture, and residential and non-residential buildings, as well as the use of electricity and heat which are obtained from electricity and heat plants. The structure of TFC in 2023 is 43.4 million tonnes of oil equivalent which is higher than in 2022 with 42.2 million tonnes of oil equivalent. By type of fuel, TFC consists of 19.4% coal, 16.3%

natural gas, 31.0% oil products, 15.0% electricity and 15.3% centralized heat. By type of sectors TFC consists of 28.2% by industry, 19.8% by transport, 45.8% by buildings and 6.2% by others.

As it can be seen from the energy balance statistics, the economy uses mostly fossil fuels with the coal on the first place. The second place takes the natural gas which is mainly associated with petroleum gas. The oil sector is one of the main contributors to the Kazakhstan's economy, playing a key role in the formation of exports, the state budget and GDP, as well as long-term economic development.

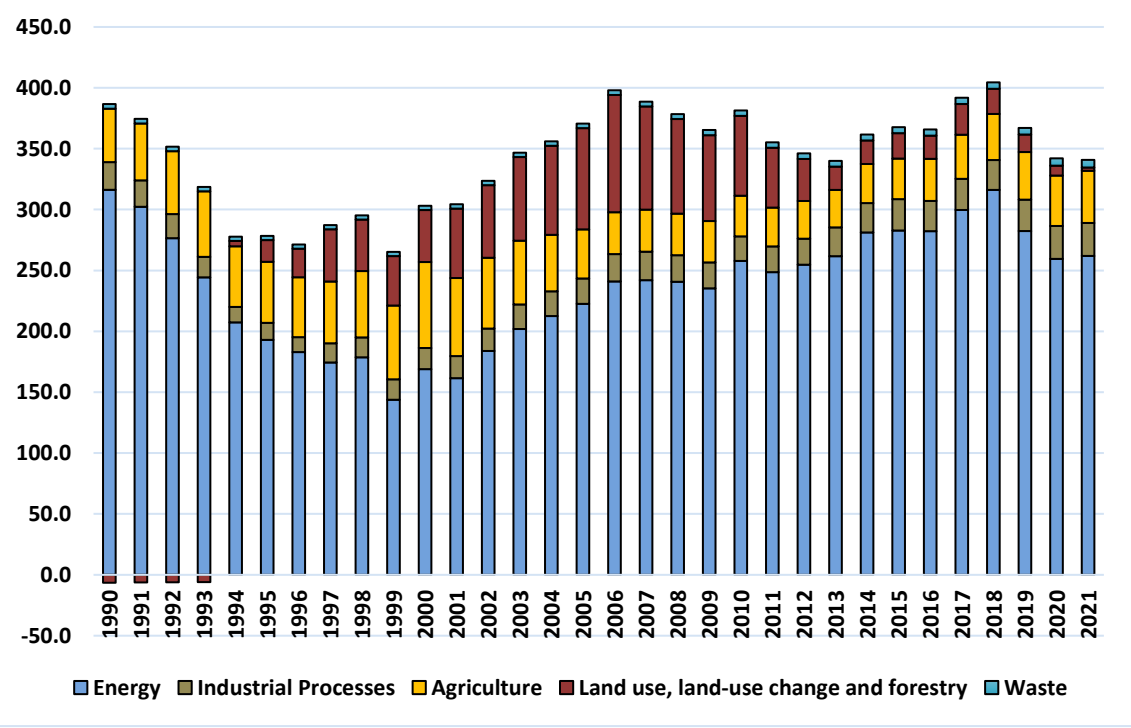
The statistical review of the world energy industry by BP in 2021 says the country possesses substantial oil reserves; ranking 12th globally with more than 30 billion barrels (3.9 billion tonnes). In 2023, according to the Ministry of energy, the country extracted 89.9 million tonnes of crude oil. Approximately 78.4% of the crude oil or 70.5 million tonnes was exported.

2.2 Greenhouse gas emissions from energy sector

The GHG emission profile of the country since the 1990 has the same dynamics as the whole economy. It starts fall within 90th of the last century, then from the beginning of this century, the emissions have recovered following the economy boost. We can see the traces of the global crises of 2008 and 2015 years that slow down the growth.

Since the 1990 year, the national GHG emissions level has the highest value in 2018 when the volume reached the 404.5 million tonnes CO2-equivalent (see the figure below). This was 6.4% higher than the previous high 1990 level of 380.2 million tonnes of CO2-equivalent. In the 2019, 2020 and 2021 the emission levels both from total country and energy sector decreased due to COVID disease.

Figure 2. *The GHG emissions of Kazakhstan by main categories, million tonnes CO2-equivalent*



Sources: National Inventory Report of Kazakhstan on GHG emissions (NIR RK, 2023)

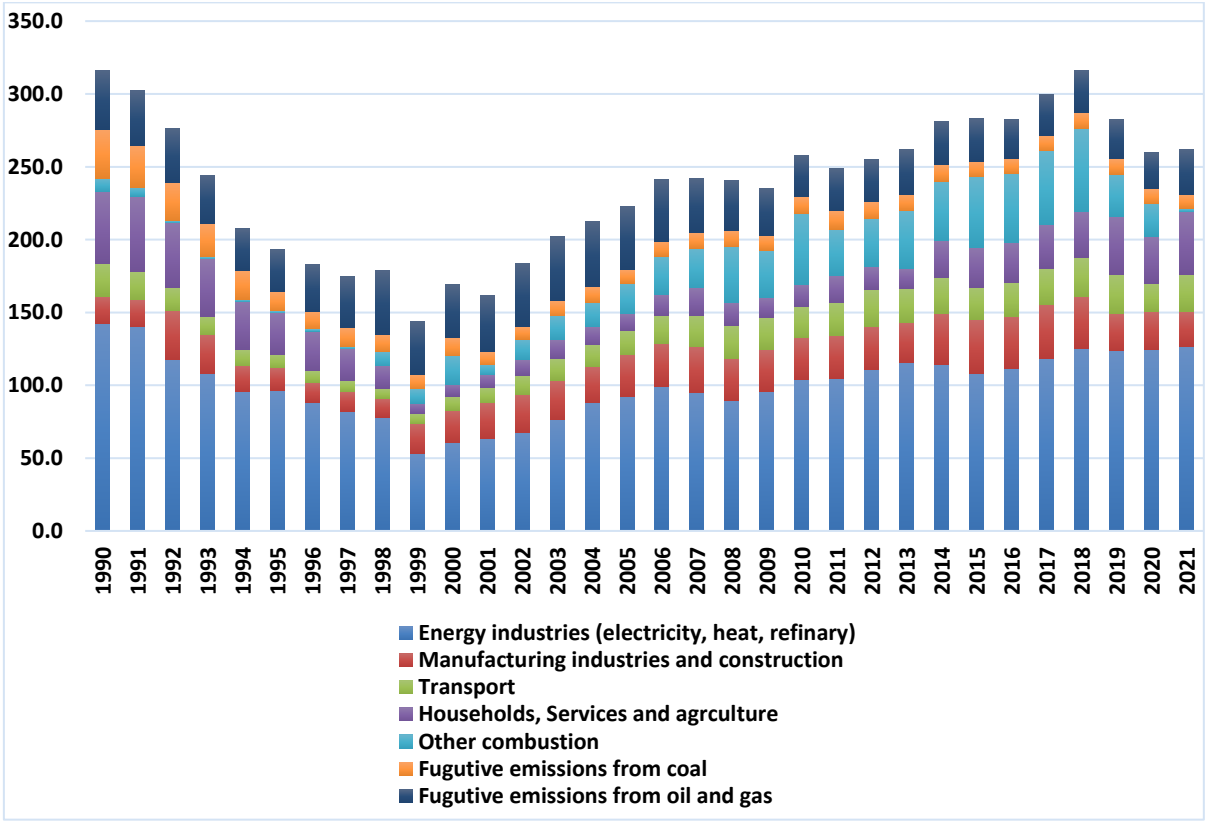
Energy sector is the main contributor to GHG emissions in Kazakhstan. According to last available national inventory of country in 2021, the energy sector emitted 261.9 million tonnes CO2-equivalent or 76.9% of national GHG emissions (340.8 million tonnes CO2-equivalent) (NIR RK, 2023).

The largest emissions in the energy sector in 2021 are produced by energy industries (electricity, heat, and refinery) and they account for at least 48.9% of all GHG emissions and amounted to 126.6 million tonnes of CO2-equivalent, which is 11.1% less than the 1990 level. This is due to the more introductions of natural gas power plants.

The second largest contributor to total emissions is the Households, services and agriculture (often this sector called “buildings”) which contribution was 16.7% or 43.1 million tonnes of CO2-equivalent. Compared to the base 1990 year, emissions have decreased by 12.7%. The GHG emissions are increasing at high rates and in a short time assumed to reach 1990 levels.

The GHG emissions from the Transport are in third place, with a share of 9.6%, or 25.2 million tonnes of CO2-equivalent. Emissions exceed the baseline of 1990 by 11.6%. The emissions in this sector increasing due to the rise of economy and the aging of cars and trucks.

Figure 3. *The GHG emissions of Kazakhstan from energy sector, million tonnes CO2-equivalent*



Sources: National Inventory Report of Kazakhstan on GHG emissions (NIR RK, 2023)

The share of GHG emissions from the category Manufacturing industries and construction amounted to 24.3 million tonnes of CO2-equivalend, which is 28.7% more than the 1990 level. However, this level is less than in previous years in the period of 2001-2018 due to COVID.

The share of the Fugitive GHG emissions tended to decrease - from 23.4% (1990) to 15.4% (2021). The GHG emissions from the fugitive emissions in 2021 amounted to 40.5 million tonnes of CO2-equivalent, which is 2.4 times less than the 1990 level.

2.3 Power sector profile

Power sector is a part of the energy sector representing the activities related to the production of electricity only or combined with heat in the case of combined heat and power (CHP) plant.

The sector is a key for the economy, driving both the current state and development prospects of all sectors of the economy. With the development of technologies in all spheres of economy and the increase in population, the need for efficient and sustainable use of electricity is becoming increasingly urgent. With the global focus on reducing carbon emissions, electricity produced from clean sources is becoming increasingly valuable.

Regulation of the power sector in Kazakhstan is carried out at the national level and is aimed at ensuring the reliability, availability and sustainability of energy supply. The main state body responsible for supervision and regulation in this area is the Ministry of Energy, which develops state policies and coordinates their implementation. A key role in the regulation of the power sector is played by the Law of the Republic of Kazakhstan "On Power Sector" (Power Law RK, 2004). This law provides legal support for the implementation of policies, including the management and distribution of energy resources, as well as licensing and tariff policy issues.

Electricity production in Kazakhstan is carried out by 222 power plants of various forms of ownership. As of January 1, 2024, the total installed capacity of power plants in Kazakhstan is 24,641.9 MW, and the available capacity is 20,428.4 MW. In 2023, 560 MW of new energy capacities were commissioned.

In 2023, electricity consumption in Kazakhstan reached 115 billion kWh, an increase of 1.8% compared to the previous 2022 year. However, electricity production remained at the 2022 level and amounted to 112.8 billion kWh in 2023. This indicates a slight increase in consumer demand with a stable level of electricity production, which may require additional measures to increase production capacity in the future to ensure a balance between supply and demand.

2.3.1 Economic Contributions of the power sector

According to the publications on national accounts of country by Bureau of Statistics (BNS RK. 2023b), in 2023 year, the Gross Domestic Product (GDP) in 2023 (according to preliminary data) amounted to 120 561 096.4 million tenge. GDP calculated at the average annual dollar exchange rate of the National Bank of the Republic of Kazakhstan amounted to 264 208.8 million US dollars. GDP increased by 5.1% in real terms.

The input of the sector «Supply of electricity, gas, steam, hot water and air conditioning», which represents the power sector, sector of heat supply and hot water and air conditioning, to the GDP was 1.3% amounted to 1 601 676.5 million tenge or 3 510.1 million US dollars. Even though the contribution is small, the real meaning of the sector is tremendous. The sector in real terms increased its output by 1.8% in comparison with 2022 year.

According to the results of 2023, the average salary in Kazakhstan was 364 295 tenge, which is 17.6% more than in 2022; in real terms, wages increased by 2.7% (BNS RK, 2023c). The average salary in sector of electricity, heat, hot water in air conditioning is 330 028 tenge which is by 9.4% less than average by economy. However, the average rise in salary by 22.9% and 7.3% in nominal and real terms are higher than the national average. This is due to policy to increase the salaries in energy supply sectors as it was suffering from low wages for many years and vanishing of qualified human resources.

The employment rate to the population aged 15 years and over in 2023 was 65.2%, and 95.3 to the labour force. The unemployment rate (according to the methodology of the International Labour Organization) was 4.7% (BNS RK, 2023c).

According to the sample employment survey for 2023, 9.1 million people were employed in various sectors of the economy of Kazakhstan, of which 6.9 million people were hired workers (75.9% of the total number of people employed in the economy), and 2.2 million people were self-employed (24.1% of the total number of people employed in the economy). The largest share of employment was observed in trade (16.7%), education (13%), industry (12.3%) and agriculture (11.9%). The 148.9 thousand people worked in the sector of electricity, heat, hot water in air conditioning in 2023 year, which is 1.64% of all employed in the country (BNS RK, 2023c).

2.3.2 Power sector pricing system

The electricity pricing system in Kazakhstan is a multi-stage mechanism regulated by the state. The main state mechanism in the power system is a tariff which is the price regulated by the State price on each stage of electricity chain: Ministries of Energy and National Economy. The purpose of the tariff system is to ensure the availability of electricity. The goals of tariff system also were to stimulate energy efficiency, to develop the electric power industry and to maintain stable operation of the system. However, if the tariff system is not set properly than it could hurt the power sector.

The current pricing system in power sector covers all stages: generation, transmission, distribution and consumption. At the generation stage, the cost of electricity depends on the type of power plant, the generation method and regional characteristics. The average tariff at the level of power plants is between 3.0 to 7.2 US cents per kWh (13.76 to 33.25 KZT per kWh).

The sum tariff for transition is 1.28 US cents per kWh (5.87 KZT per kWh) and consist of:

- The transmission of electric energy - 0.76 US cents per kWh (3.47 KZT per kWh);
- The use of the national electric grid - 0.43 US cents per kWh (2.00 KZT per kWh);
- The technical dispatching - 0.07 US cents per kWh (0.34 KZT per kWh);
- The organization of balancing - 0.01 US cents per kWh (0.06 KZT per kWh);

At the distribution stage, the level of tariffs for the stage of distribution is set differently by the regions and settlements. On the consumer’s level, the different tariffs are set according to the categories of consumers: households, commercial companies and public organizations.

As mentioned earlier, the tariff system can make problems if not set properly.

The most of power sector infrastructure in Kazakhstan was built in the 60-80s of the last century and more than two-thirds of it is worn out at the current stage. In addition, cities are growing, the population is increasing, which leads to an increasing load on the networks and increases wear.

On November 27, 2022, due to damage on the heating networks, the Ekibastuz CHP stopped a supply of heat to the city, which left the people without heat, 149 multiapartment buildings, 114 private houses and 15 social facilities were left without heat. To help the situation, people from all over the country began to collect heaters, blankets, and essential items, and the military even pitched tents and set up soldiers' kitchens.

The situation in Ekibastuz highlights the urgent issue of aging and under-maintained energy infrastructure. Much of the city's energy equipment, including its power plants and heat supply systems, has suffered from years of underinvestment, leading to frequent breakdowns and inefficiencies. This incident in Ekibastuz raises broader questions about the state of energy infrastructure throughout Kazakhstan. The economic implications of inefficient and unreliable energy systems are far-reaching, affecting both residential and industrial users.

To address these challenges, substantial investments in upgrading energy infrastructure are urgently needed. Modernizing power plants, heat supply networks, and related equipment can improve reliability and efficiency.

Kazakhstan's public utility infrastructure needs to be modernized and repaired; to attract highly qualified personnel to the industry, employees need to be paid higher salaries. All these measures are necessary to provide population with high-quality public utility services. To solve the problems, the country put in place a "Tariff in Exchange for Investments" program, according to which the goal is to attract investments into the infrastructure modernization and renovation. To achieve the goal the tariffs or prices will be increased from current levels. It is planned to attract large-scale investments in 2023-2029 to modernize utility networks for electricity, heat, water supply, and sanitation and to reduce wear by 20% by 2029.

3. Renewable and alternative energy sectors in Kazakhstan

Kazakhstan, rich in fossil fuel resources and a global leader in uranium production, is at the moment of diversification of its energy mix and reduce greenhouse gas emissions. The renewable and alternative energy sectors, including wind, solar, hydro, and nuclear energy, are rapidly gaining prominence in Kazakhstan’s energy strategy as the country commits to ambitious decarbonization targets and sustainable economic growth.

3.1 Renewable energy sector

Kazakhstan has consistently advanced its commitment to renewable energy and climate action through progressive national policies and participation in global environmental agreements. A pivotal milestone was the introduction of the Law on Supporting the Use of Renewable Energy Sources (RES Law RK, 2009) in 2009, which laid the groundwork for a robust regulatory framework to foster the development and integration of renewable energy across the country.

In 2013, Kazakhstan adopted the "Green Economy Concept," (Green Concept RK. 2013) establishing a strategic vision for transitioning to a more sustainable economic model with renewable energy at its core. This long-term framework set ambitious targets to generate 15% of the country's electricity from renewable sources by 2030, rising to 30% by 2040 and 50% by 2050, underscoring the nation's commitment to integrating renewable energy into its sustainable development strategy.

In 2014, Kazakhstan approved fixed tariffs for renewable energy projects, offering financial incentives and creating a stable investment environment that accelerated renewable energy adoption. In 2018, the fixed tariffs were changed to an auction mechanism, promoting transparency and competition, which encouraged private sector participation.

Over the past five years, 260 companies from 13 countries, including Kazakhstan, Russia, China, Turkey, France, Bulgaria, the UAE, Italy, the Netherlands, Germany, Singapore, Malaysia, and Spain, have participated in Kazakhstan's renewable energy auctions. These auctions are expected to facilitate the deployment of 6,670 MW of renewable energy capacity by 2032, demonstrating significant international interest and commitment to the country's energy transition. However, the Ministry of Energy's plans for the development of flexible generation capacity remain unclear, posing challenges to effectively balancing renewable energy integration with grid stability.

In 2020, renewable energy projects were included in the list of priority investment projects in Kazakhstan, granting them access to significant investment preferences. These preferences include exemptions from customs duties and value-added tax on imported goods, as well as state-provided in-kind grants. The maximum size of these grants can constitute up to 30% of the total investment volume and may cover land plots, buildings, equipment, and other essential assets.

In addition to investment preferences, priority projects in renewable energy benefit from substantial tax incentives under Article 290 of the Entrepreneurial Code of Kazakhstan. These include a 100% reduction in calculated corporate income tax, application of a zero coefficient to land tax rates, and property tax exemptions with a 0% calculation base.

By integrating global agreements and advancing its regulatory framework, Kazakhstan has established a robust foundation for achieving renewable energy and sustainability objectives.

3.2 Current profile of renewable sector

According to Ministry of energy, in 2023, renewable energy facilities in Kazakhstan generated 6 675 million kWh of electricity. The breakdown by type of renewable energy sources is as follows: wind power plants produced 3 825 million kWh, solar power plants – 1 854 million kWh, hydroelectric power plants - 994 million kWh, and bioenergy plants - 2.71 million kWh.

At the end of 2023, the share of electricity generated by renewable sources amounted to 5.92% of the total electricity production in the country. This significantly exceeded the planned figures by 18.4%, since the level of 5% was expected to be reached. Such data reflects the active development and integration of renewable energy sources into the energy system of Kazakhstan.

There were 144 renewable energy facilities operating in the Republic of Kazakhstan at the end of 2023 with an installed capacity of 2,868.6 MW:

- 57 wind power plants with a capacity of 1,394.6 MW;
- 45 solar power plants with a capacity of 1,202.61 MW;
- 39 hydroelectric power plants with a capacity of 269.605 MW;
- 3 bioelectric power plants with a capacity of 1.77 MW.

According to the forecast balance for 2024-2030 from Ministry of Energy, the electricity production and consumption gap representing the deficit is assumed to be 13.5 billion

kWh by the 2030 year. The forecasted renewable energy is not enough to cover this deficit.

Table 3. Forecast balance of production and consumption of electricity in the Unified Energy System of the Republic of Kazakhstan, billion kWh

	2024	2025	2026	2027	2028	2029	2030
Consumption	120.6	125.1	130.7	136.8	143.0	149.3	155.9
Production	118.3	121.8	136.3	141.9	142.2	142.5	142.5
Existing	114.7	113.7	111.7	110.6	110.6	110.6	110.6
Planned	3.6	8.1	24.5	31.3	31.6	31.8	31.8
Including renewables	0.78	1.20	6.12	6.12	6.12	6.12	6.12
Deficit (+), excess (-)	2.4	3.3	-5.6	-5.1	0.7	6.9	13.5

Source: KEGOC Electric power industry of Kazakhstan (KEGOC, 2024)

The perspectives of the renewables in Kazakhstan are promising, driven by the country's strategic commitment to green energy transition. With vast solar and wind potential, particularly in the southern and central regions, Kazakhstan has the opportunity to significantly diversify its energy mix. The share of renewables in the country’s energy mix has steadily increased, supported by key legislative frameworks and policy measures. Mechanisms such as fixed tariffs for renewable energy projects, introduced in 2014, provided the financial stability and incentives necessary to attract investment into the sector.

Further progress was driven by the introduction of an auction mechanism in 2018, which fostered competition among developers and optimized the cost-efficiency of projects. This transparent system allowed for the selection of the most economically viable renewable energy initiatives, facilitating the deployment of solar, wind, and hydropower projects across the country.

Kazakhstan's alignment with the Paris Agreement in 2016 further propelled its renewable energy ambitions. The adoption of the "Strategy for Achieving Carbon Neutrality of Kazakhstan by 2060" in 2023 marked another critical milestone, setting an ambitious roadmap for expanding renewable energy, enhancing energy efficiency, and adopting innovative technologies.

Kazakhstan’s renewable energy strategy is built on market-driven mechanisms to support its ambitious goals. Recognizing the complexities of integrating renewables into its energy system, the country considers measures and initiatives driving the renewable.

To effectively integrate renewable energy sources, Kazakhstan start consider projects with flexible capacity with energy storage. These measures address the intermittency challenges of solar and wind energy by improving grid reliability and ensuring a stable energy supply. To support the stability, there is need for introduction of forecasting tools for renewable energy production and re-establish differentiated tariffs based on peak and off-peak consumption periods.

The energy storage systems are being considered to be piloted to tackle the daily and seasonal variability of renewable energy generation. Kazakhstan aims to maximize renewable energy utilization, enhance grid stability, and ensure uninterrupted supply during peak demand periods.

The expansion of distributed generation by households and businesses will play a key role in advancing renewable energy adoption at a decentralized level. By enabling consumers to produce their own energy and sell surpluses back to the grid,

Kazakhstan can enhance energy self-sufficiency and reduce transmission losses. In June 2024, amendments to Kazakhstan's law on supporting renewable energy sources introduced significant advancements for small-scale renewables (RES Law RK. 2009). The updates include raising the installed capacity limit for small-scale renewables to 200 kW, improving conditions for net-consumer grid connections, and streamlining the purchase of surplus electricity at regulated prices. These measures aim to boost small-scale renewable adoption across regions, promote energy affordability, and align with the declining costs of renewable technologies.

Kazakhstan emphasizes the importance of legislative stability, transparent auction practices, and investor confidence to accelerate renewable energy deployment. Clear and predictable policies are crucial for attracting domestic and international investment. These favourable conditions will ensure the scalability of renewable energy projects and foster long-term growth in the sector.

Kazakhstan’s strategic approach reflects its commitment to a green transition and carbon neutrality. By addressing systemic challenges, such as regulatory clarity and infrastructure upgrades, the country is setting the stage for a robust and resilient renewable energy sector.

3.3 Nuclear energy sector

Kazakhstan's nuclear sector has a rich history. During the Soviet era, Kazakhstan was a crucial site for nuclear activities due to its abundant uranium deposits and vast, sparsely populated lands, which were convenient for nuclear testing and fuel production.

Kazakhstan's involvement in the nuclear sector began in earnest in the mid-20th century when it became a significant part of the Soviet Union's nuclear ambitions. The Semipalatinsk Test Site, located in north-eastern Kazakhstan, was one of the primary nuclear testing grounds for the Soviet Union. From 1949 to 1989, the site witnessed over 450 nuclear tests, which had profound environmental and health impacts on the local population and ecosystem.

In parallel, Kazakhstan emerged as a leading uranium producer, supplying a substantial portion of the Soviet Union's uranium needs. The discovery of large uranium deposits in regions such as Mangyshlak, Shu-Sarysu, and Syrdarya spurred the development of extensive mining operations. By the time of the Soviet Union's dissolution, Kazakhstan was producing significant quantities of uranium, making it a key player in the global nuclear material supply chain.

The nuclear power also has roots in the Soviet era, when in 1964 in the Mangyshlak region of country, the construction of fast neutron nuclear reactor BN-350, located in Aktau city, begins with physical startup happing in 1972 and power startup in 1973. The abbreviation BN-350 formed from the words “fast neutrons” in Russian language and 350 is electrical capacity of the reactor unit. The BN-350 fast neutron reactor was a pioneering sodium-cooled fast breeder reactor designed primarily for electricity generation and desalination of seawater; it produced up to 350 megawatts.

The reactor also played a crucial role in the development and testing of fast reactor technology. In 1999, the government of Kazakhstan has made a decision to decommission BN-350 (Resolution RK, 1999). The decommissioning of BN-350 has provided valuable insights into fast reactor technology and management of radioactive materials.

Following Kazakhstan's independence in 1991, the country inherited a substantial nuclear legacy. Kazakhstan took decisive steps to manage and repurpose its nuclear

legacy. One of the most significant moves was the closure of the Semipalatinsk Test Site in 1991, followed by extensive remediation efforts to mitigate the environmental damage. Kazakhstan also voluntarily relinquished the nuclear weapons it inherited from the Soviet Union, transferring them to Russia and 13 December 1993 joining the Treaty on the Non-Proliferation of Nuclear Weapons (NPT) as a non-nuclear-weapon state (MFA RK, 2019).

The issue of building a nuclear power plant in Kazakhstan has been at the stage of discussions in society since 1997, until the September 2023, when the President announced a forthcoming referendum in 2024 to decide on building the country's first nuclear power plant. The referendum was announced to be in 6 of October 2024. The date was set by President’s address to the nation in September 2024.

3.3.1 Current profile of nuclear sector

Kazakhstan has 12% of the world's uranium resources and in 2022 produced 21,200 tonnes (WNA, 2023). Kazakhstan ranks second in the world in terms of proven reserves of natural uranium. About 14% of all proven world reserves are concentrated in the subsoil of the Republic of Kazakhstan. The total explored reserves of the country are estimated at over 700 thousand tonnes (ME RK, 2022).

Kazakhstan has been an important source of uranium for more than 50 years and became the world's largest uranium producer in 2009 with almost 28% of world production, then 33% in 2010 rising to 40% of global production in 2023 (Kazatomprom. 2024a). In 2023, uranium production amounted to 21 112 tonnes (Kazatomprom. 2024b) with average price of 52.06 USD per pound. It expects 2024 production to be 21,000-22,500 tonnes.

Uranium mining in Kazakhstan is carried out only by the method of in-situ recovery, which is the most environmentally friendly and the lowest cost method. Currently, all Kazakhstani uranium is exported to the world market, primarily to China, France, Russia, Canada and other.

Uranium mining marks the beginning of the nuclear fuel cycle (NFC). Kazakhstan is actively involved in other stages of this cycle, benefiting from access to uranium isotopic enrichment services amounting to up to 2.5 million separative work units (SWU) annually. Additionally, Kazakhstan manufactures uranium oxide powder and uranium dioxide fuel pellets, adding significant value to its nuclear products.

Kazakhstan is investigating investment opportunities in stages of the open nuclear fuel cycle that offer substantial long-term value addition. On November 10, 2021, a new plant dedicated to producing finished nuclear fuel assemblies was inaugurated at the JSC Ulba Metallurgical Plant.

All the activities in the nuclear sector currently are done within the national atomic company Kazatomprom which is set up in 1997 and owned by the government. Later on, the company becomes part of national wealth fund Samruk-Kazyna. Kazatomprom Company controls all uranium exploration and mining as well as other nuclear-related activities, including imports and exports of nuclear materials. Currently, Kazatomprom Company has 36 subsidiaries, affiliated and other companies with personnel of 21554 persons.

In November 2018 Kazatomprom was taken public with 15% of its shares placed on the Astana International Exchange and the London Stock Exchange.

There are governmental bodies, non-governmental and research organizations and that present in the nuclear sector of Kazakhstan such as:

- The Committee for Atomic and Energy Supervision and Control of the Ministry

of Energy of RK
- The Institute of Nuclear Physics
- The Nuclear Technology Safety Center
- Kazakhstan Nuclear Power Plants JSC
- The National Nuclear Center of the Republic of Kazakhstan
- The Institute of Atomic Energy of the National Nuclear Center
- The Institute of Radiation Safety and Ecology
- The Nuclear Society of Kazakhstan

3.4 National debates on the role of nuclear power

The national debate on the role of nuclear power in Kazakhstan resembles the global discourse, reflecting a balance between recognizing its potential benefits and acknowledging significant challenges. Nuclear power's future is uncertain despite its capability to generate emissions-free energy. High initial costs, extended development periods, and frequent delays make nuclear projects less competitive compared to quicker alternatives like natural gas or modern renewable energy sources. Additionally, public opposition in numerous countries further complicates its adoption. This uncertainty could lead to billions of tonnes of additional carbon emissions.

The deployment of nuclear power in Kazakhstan presents both significant opportunities and formidable challenges. As the country strives to transition towards green industrialization, understanding these challenges is crucial for developing effective policies and strategies.

3.4.1 Challenges

Opposition to nuclear power in Kazakhstan centers on several significant concerns. Foremost among these is the issue of nuclear safety. Historical incidents such as the Chernobyl and Fukushima disasters have left an impact. The own history with nuclear testing at the Semipalatinsk Test Site has compounded these fears.

Another major concern is the long-term management of radioactive waste. Opponents argue that the risks associated with the storage and disposal of nuclear waste pose significant environmental and health hazards. They also highlight the high initial costs and lengthy development timelines associated with nuclear power plants, which may divert resources from the development of more rapidly deployable renewable energy sources such as wind and solar.

Public acceptance is another critical issue. Gaining the trust and support of the population requires transparent communication, robust regulatory frameworks, and stringent safety measures. The government's ability to address these concerns will be crucial for the successful integration of nuclear power into Kazakhstan's energy strategy.

Concerns about the water levels in Balkhash Lake and the high costs associated with nuclear power plants are significant issues for Kazakhstan's opponents. The decreasing water levels in Balkhash Lake raises environmental and sustainability challenges, particularly given the substantial water requirements for cooling. Additionally, the high capital costs of constructing nuclear power plant present financial challenges, potentially impacting the country's economic stability. These concerns necessitate careful consideration and strategic planning to ensure that energy development is both environmentally and economically sustainable. These critical issues will be addressed in detail in later chapter related to the scenario analysis.

3.4.2 Opportunities

The national debate in Kazakhstan reflects the need to balance these competing perspectives. Proponents must address the legitimate concerns of opponents by ensuring that safety and waste management issues are tackled. Transparency, public engagement, and adherence to international best practices will be essential in gaining public trust and demonstrating that nuclear power can be a safe and effective component of energy transition.

While the challenges are substantial, nuclear power also offers several opportunities for Kazakhstan's industrialization and green transition. Proponents of nuclear power in Kazakhstan emphasize several key points.

This strategic advantage provides Kazakhstan with the raw materials needed to develop a robust nuclear energy program. Proponents argue that nuclear power can play a critical role in diversifying Kazakhstan's energy mix. This diversification is seen as vital for achieving the country's long-term climate goals. Nuclear power can provide a stable and reliable source of energy, which is essential for industrial development. As an emissions-free energy source, nuclear power can reduce Kazakhstan's greenhouse gas emissions.

Supporters point to the potential economic benefits of developing nuclear power. It can create high-skilled jobs, stimulate technological innovation, and attract foreign investment. Developing nuclear power can contribute to economic diversification by creating new industries and jobs.

Careful planning, robust safety measures, and clear communication, Kazakhstan can leverage the opportunities nuclear power presents to achieve its goals of green industrialization and sustainable development. Balancing these challenges and opportunities will be a key to successfully integrating nuclear power into the country's energy strategy.

South Korea serves as a model of successful nuclear power sector development. Over the past few decades, South Korea has built a robust and reliable nuclear energy program. In the 1970, the country made strategic movement into developing a stock of nuclear power plants to satisfy their growing energy demands. In 2022, 26 reactors provide about 27.6% of South Korea's electricity from 25 825 MW of Nuclear power plants (176 TWh from 638 TWh).

In July 2022, the South Korean government laid out a new energy policy that aims to maintain share of nuclear energy at a minimum of 30% by 2030. The new policy also aims to strengthen exports of nuclear reactors as the "growth engines". It sets the goal of exporting 10 nuclear power plants by 2030, as well as the development of a Korean SMR design (WNN, 2024).

This success can be attributed to several key factors such as governmental support, strong regulatory framework, technological innovation, standardization, efficiency, international collaboration.

The government has provided clear policies, substantial funding, and long-term planning to foster the growth of nuclear energy. A stringent regulatory framework, overseen by the Korea Institute of Nuclear Safety, ensures that all nuclear activities meet rigorous safety and environmental standards. This robust regulatory environment has built public trust and maintained high safety standards, essential for the sustainable development of nuclear power.

Kazakhstan can draw lessons from South Korea's successful development of its nuclear power sector. The most key lesson is strong government support and strategic planning. South Korea's success is largely due to consistent government support and

strategic long-term planning. Kazakhstan should develop a comprehensive nuclear energy policy.

Other key action on radio phobia in society is effective public communication and education as it was done in South Korea. Kazakhstan should implement transparent public engagement strategies, including regular updates, educational programs, and open forums to address public concerns and build trust in nuclear energy.

South Korea actively participates in international nuclear safety and regulatory networks, adopting global best practices. Kazakhstan should engage with international bodies, participate in peer reviews, and adopt best practices from leading nuclear countries to make the best use of its resources while decarbonizing its future in the safest way possible.

By focusing on these key areas, Kazakhstan can effectively develop a sustainable and robust nuclear power sector, enhancing energy security, supporting sustainable economic growth, and reducing its carbon footprint.

4. Scenario Analysis of Energy sources

The cost of construction of different energy sources are affected by the technology used, labour costs, existing experience in similar type of power plant construction, economies of scale, simplified licensing, etc.

Global experience shows that overnight costs for the construction of new nuclear power plant capacities range from an average of US$2,157 in South Korea to US$6,920 in Slovakia. When taking into account investment costs, the cost is comparatively higher. The average CAPEX for nuclear power plant is taken as 3606 million US dollars per 1 GW.

Table 4. Capital costs of construction of nuclear power plants

Country	Overnight costs ($/kW)	Investment costs ($/kW)		
		3%	7%	10%
France	4 013	4 459	5 132	5 705
Japan	3 963	4 402	5 068	5 633
South Korea	2 157	2 396	2 759	3 066
Russia	2 271	2 253	2 904	3 228
Slovakia	6 920	7 688	8 850	9 837
USA	4 250	4 721	5 435	6 041
China	2 500	2 777	3 197	3 554
India	2 778	3 086	3 552	3 949
Average	3 607	4 099	4 612	5 127

Sources: International Energy Agency, Projected Costs of Generating Electricity 2020 Edition (IEA, 2020)

The cost of construction of nuclear power plant is full of uncertainty.

Capital/investment costs for the construction of a nuclear power plant in the Jizzakh region of Uzbekistan average 4583 USD dollars (at a cost of 11 billion USD dollars and a capacity of 2.4 GW), and for a nuclear power plant in Turkey – 4167 USD dollars (at a cost of 20 billion USD dollars and a capacity of 4.8 GW). For Kazakhstan, these estimated have been in the range from 4167 till 6250 USD dollars (2.4 GW nuclear power plant has been estimated for 10-15 billion USD dollars).

In the Kazakhstan information space, the issue of comparing the cost of wind, solar and hydro energy to nuclear energy is often raised. Often, the only capacity costs are

compared without taking into account many other key technical economical parameters such as capacity factor, time of exploitation, and many others.

The capacity factor is the coefficient of use of the installed capacity, i.e. what percentage of energy is generated from the declared capacity. The global capacity factor of nuclear power plants is 79%, which is significantly higher than the same indicator for hydropower (59%), wind power (24%), and solar power (16%) in Kazakhstan. That is, the efficiency of energy generation at a nuclear power plant is significantly higher than that of renewable energy sources (PwC, 2021).

However, if the capacity factor is considered, in order to generate the same amount of electricity as a nuclear power plant with a capacity of 1 GW, it is necessary to build 1.3 GW of hydro, 3.4 GW of wind, and 4.9 GW of solar generation. This disproportion significantly increases the costs of renewable energy sources. The cost comparison is provided below in the table 5.

Table 5. Capital costs of construction of nuclear power plants and renewable energy sources taking into account the capacity factor

Type of energy	Capacity factor	Electricity output, billion kWh	GW	CAPEX (USD dollars per kW)	Cost, million USD dollars
Nuclear	79%	6.92	1.0	4 250	4 250.0
Hydro	59%	6.92	1.3	3 600	4 820.3
Wind	24%	6.92	3.4	1 391	4 578.7
Solar	16%	6.92	4.9	995	4 912.8

Note: CAPEX is indicated as overnight costs, i.e. excluding loan servicing costs

Sources: Author's calculations

From the table 5, the next observation can be seen. The cost of building wind and solar power plants is 2.5 and 3.6 times cheaper, respectively, than a nuclear power plant (International Energy Agency, 2020). However, taking into account the capacity factor indicator, the cost of building renewable energy sources fluctuates between 4000 and 5000 million US dollars, while the cost of building a nuclear power plant could be around 4 250 million US dollars – the most expensive overnight cost for USA (See table 4).

5. Policy Recommendations

The development of a robust clean power sector in Kazakhstan presents a unique opportunity to reconstruct outdated power system, enhance energy security, support economic growth, and contribute to global efforts in reducing carbon emissions. However, achieving these goals requires a comprehensive and strategic approach to policy-making. Based on the analysis of the energy system with focus of green development of power sector the number of key policy recommendations can be elaborated. These recommendations are informed by best practices from international experience and tailored to Kazakhstan's unique context, taking into account environmental concerns, economic feasibility, and technological advancements.

By implementing these policies, Kazakhstan can ensure the safe, sustainable, and efficient development of its clean power sector, ultimately strengthening its position in the global energy landscape. The key policy recommendations are provided lower.

- Development a master plan for energy system development with decarbonization goals, integrating renewable energy deployment and modernization needs;
- Improvement renewable energy forecasting, reinstate differentiated time-of-use tariffs, and encourage energy-saving behaviors;
- Development a phase-out plan for decommissioning coal facilities with defined timelines, required investments, and owner compensation mechanisms;
- Consideration of constructing gas-fired combined cycle plants for balancing the energy system and increasing gas resource accessibility for flexible power generation;
- Development of a roadmap for transitioning coal-based combined heat and power plants to gas fuel;
- Development of strategies for renewable energy growth, addressing siting, energy storage, and network alignment;
- Launching pilot projects for energy storage systems to address renewable intermittency and daily load balancing;
- Formulation long-term strategy for nuclear energy, including small modular reactors, to supplement the energy mix;
- Implementation demand-side management programs and advanced digital technologies for optimizing energy use and reducing transmission losses;
- Building of national research and engineering expertise to support energy transition efforts and adjust strategies in line with global trends.

These recommendations aim to provide a comprehensive roadmap for transforming Kazakhstan’s power sector, fostering sustainability, and meeting decarbonization goals by leveraging innovative technologies, regulatory reforms, and targeted investments.

6. Conclusion

Kazakhstan is on the way of transitioning towards a sustainable, low-carbon energy future. The exploration of clean green power as a key component of this transition underscores the need for a multi-faceted approach that balances economic, environmental, and social considerations. As the country grapples with the twin challenges of ensuring energy security and reducing greenhouse gas emissions, renewable energy sources and nuclear power presents a promising opportunity.

The development of a robust clean power sector in Kazakhstan offers the potential to diversify the national energy mix, enhance energy security, and contribute to significant reductions in carbon emissions.

With abundant renewable energy resources such as wind, solar, and with less potential of hydropower, Kazakhstan holds significant position to become a leader in clean energy production. Capitalizing on this potential will necessitate overcoming challenges such as intermittency issues, enhancing grid infrastructure, and fostering a supportive investment climate through stable policies and incentives. At the same time, with its substantial uranium resources and existing nuclear expertise, Kazakhstan is well-positioned to leverage these advantages in the global push towards decarbonization. However, the successful integration of nuclear power will require addressing public concerns about safety, managing high initial costs, and establishing a comprehensive regulatory framework that ensures stringent safety and environmental standards.

Key recommendations, elaborated for Kazakhstan's energy transition, emphasize the need for a robust regulatory framework, long-term financing mechanisms, and market-based approaches to foster renewable energy adoption and decarbonization. These

include enhancing grid flexibility, piloting energy storage systems, incentivizing distributed generation, and reforming tariffs to reflect environmental costs while supporting vulnerable populations. Additionally, the development of hydrogen energy, modernization of coal and gas infrastructure for flexibility, and expansion of renewable-friendly policies are vital.

In conclusion, the path to clean power is full of both opportunities and challenges. By implementing informed policy measures, engaging in transparent public dialogue, and adhering to international safety standards, Kazakhstan can harness the potential of energy power sector to achieve its ambitious climate and energy goals. This strategic approach will not only foster sustainable development but also position Kazakhstan as a leader in green energy innovation within the Central Asia region.

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