



The State of the Art of the Mining and Metallurgical Industry in Kazakhstan and Future Perspectives: A Systematic Review

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Abstract

This review discusses the current situation of Kazakhstan's mining and metallurgical industry, emphasizing the potential and challenges confronting the sector. It offers a detailed analysis of the industry's current situation, considering issues related to the economy, society, regulations, infrastructure, and the environment. Additionally, the evaluation explores the industry's future direction, particularly considering the National Development Plan in place until 2029. Key aspects include the importance of environmentally responsible practices, foreign investments' role, and technical improvements' impact on production and efficiency. The analysis also highlights Kazakhstan's abundant mineral resources, such as copper, gold, iron, lead, and uranium, and examines mining operations associated environmental and social impacts. Government policies and regulations are significant factors shaping the sector's development. The National Development Plan outlines several strategic objectives, including increasing production, attracting foreign investment, and promoting environmentally responsible practices. The review concludes with recommendations for overcoming obstacles and maximizing opportunities to achieve sustainable growth in Kazakhstan's mining and metallurgical sector. This systematic review, a valuable resource, will greatly benefit stakeholders, researchers, policymakers, and potential investors interested in the future of this crucial industry.

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1. Introduction

In recent years, the extractive and processing industries have driven steady growth in Kazakhstan's key economic indicators. Kazakhstan's mineral resources include oil, natural gas, coal, iron ore, copper, gold, uranium, and other metals and minerals.^[1] Since the collapse of the Soviet Union in 1991, both the mining and metallurgical industries have undergone a significant transformation. Considerable efforts have been made to transition to a market-oriented economy. Over the past few decades, Kazakhstan has implemented various reforms and initiatives to modernize and diversify its mining and metallurgical complex (MMC), attract foreign investments and enhance global competitiveness. Kazakhstan's industry boasts several key advantages. The country is rich in diverse mineral resources, including oil and

gas deposits in the western region, coal deposits in the north and south, iron, polymetallic ores, and gold in the central, south, and north regions, and phosphates in the southern part of the country. The industrial infrastructure, along with production centers, also contributes to the sustainable development of the mining and metallurgical industry. In the first half of 2023, Kazakhstan saw a remarkable influx of \$13.3 billion in foreign direct investment (FDI). The top contributors were the Netherlands, the US, Switzerland, Russia, China, South Korea, Belgium, France, the UAE, and Luxembourg.^[2]

2. An overview of the historical development of the Mining and Metallurgical industry

Kazakhstan's mining and metallurgical industry has evolved through three major periods. The first period corresponds to the Soviet era, which lasted from the early 1920s to 1991. During this period, substantial efforts were made to industrialize on a large scale and explore mineral resources, and Kazakhstan became the USSR's largest coal producer. Several industries were established, including the Aktobe Chemical Plant, Balkhash Copper Smelter, Karaganda Coal

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Basin, Shymkent Lead Plant, and Turkestan-Siberian Railway. In 1939, Kazakhstan contributed 84.8% of the USSR's total lead production and 16.2% of its copper production. During World War I, the Ust-Kamenogorsk Zinc Plant, Aktobe Ferroalloy Plant, Tekeli Lead-Zinc Plant, and Ust-Kamenogorsk Zinc Plant were constructed.

The Kazakhstani mining industry experienced a second growth period from the early 1990s to the 2000s, following the collapse of the Soviet Union. Following the breakup of the Soviet Union in 1991, Kazakhstan transitioned from a centrally planned economy to a market-oriented economy. Kazakhstan faced economic challenges in the early years of independence, as it sought to privatize state-owned companies, particularly those in mining and metallurgy, and to overhaul its industrial base. In 1967, copper from the Balkhash Mining and Metallurgical Combine was approved as the quality standard by the London Non-Ferrous Metals Exchange. Despite early difficulties, Kazakhstan eventually opened its economy to foreign investment and implemented reforms to attract resources and expertise to the mining sector.

In the early 2000s, Kazakhstan launched programs to modernize and diversify its mining and metallurgical industries. The government enacted laws to encourage foreign investment, technological innovation in the sector, and joint ventures with multinational corporations. Major international mining organizations such as Rio Tinto, Glencore, and Eurasian Resources Group (ERG) have made significant investments in Kazakhstan's mining enterprises, helping to construct new mines and modernize existing facilities. Kazakhstan's entry into the World Trade Organization (WTO) in 2015 enhanced trade and investment prospects in the mining and metallurgical sectors. The government continues to focus on improving efficiency, sustainability, and value addition in its mining and metallurgical operations, with the goal of leveraging its substantial mineral resources for economic growth.

3. Major mineral deposits of Kazakhstan

3.1 Oil and Gas sector

Kazakhstan possesses a wide range of natural resources, making it one of the world's top producers and exporters in various sectors of the mining industry.

Kazakhstan has significant oil and gas deposits, particularly in the western regions, such as the Caspian Sea basin. The Tengiz field produced 28.9 million metric tons (230.6 million barrels^[1]) of crude oil. The Karachaganak field produced 142.698 million barrels of oil equivalent in 2023.^[3] Furthermore, the Kashagan field set a record by producing approximately 18.8 million tons in 2023.^[4] These fields are among Kazakhstan's major oil and gas reserves, accounting for a significant portion of the country's hydrocarbon production. Kazakhstan's oil and gas sector has attracted significant foreign investment, with multinational energy companies collaborating with Kazakhstani firms in its development.

3.2 The Copper Mining Process

KAZ Minerals operates six producing mines. The three mines in the East Region are underground, while the Bozshakol, Aktogay, and Bozymchak mines are open-pit operations. The mines generally contain sulfide ores, with by-products that vary in quantity and proportion across the different mines. The main by-products include zinc, silver, gold, and molybdenum. Each step in the copper processing focuses on progressively removing unwanted materials, turning ore into concentrate and eventually into finished metals.

The Aktogay project began producing copper cathode from oxide ore via SX/EW in December 2015, and the main sulfide concentrator at Aktogay began commissioning in December 2016. The Aktogay expansion project, aimed at doubling sulfide processing capacity, was officially launched in October 2021, with the first shipment to customers in the same month. Bozshakol began producing copper concentrate from sulfide ore in February 2016.

Balkhash's copper production line is presented in Fig. 1, in which from 1952 to the present day, the workshop has shipped 12 million 983 thousand 981 tons of cathode copper.



Fig. 1 Balkhash copper production line by cathode method.

In 2010, silver bars produced by Balkhash metallurgists received the international "Good Delivery" status, which is awarded to standard bars of excellent quality, high purity, and a mark from a reputable, accredited manufacturer.

In 2012, Kazakhmys Smelting LLP began operating as a separate business unit within the structure of Kazakhmys, based on the Metallurgical Complex. This division included the Balkhash copper smelter, the Zhezkazgan copper smelter, the Kazkat plant, a workshop for copper and enamel wire production, and an oxygen production plant.

3.3 Gold

Gold mining is a crucial sector in Kazakhstan, with significant reserves distributed throughout the country. Major gold-producing regions include East Kazakhstan, Karaganda, and Akmola, where both large-scale and artisanal mining

operations are active. Kazakhstan's gold production contributes to both domestic demand and export revenues. According to the World Gold Council, as of June 1, 2022, Kazakhstan's gold reserves amounted to 373.4 tons. At that time, the country ranked 14th among the world's largest gold-producing nations. It is notable that in the first quarter of 2022, Kazakhstan held the largest gold reserves among Central Asian countries. Kazakhstan has nearly 200 gold deposits. Most of these deposits are located in the east and northwest of Kazakhstan. Smaller deposits are also present in the northeast and central regions of Kazakhstan.

Kazakhstan's copper reserves are recognized globally. The majority of Kazakhstan's copper ore—92%—is exported. Kazakhstan's richest mining sites are primarily located in the center, near Zhezkazgan.

Kazakhstan's mineral map includes rare metals such as tungsten, antimony, vanadium, molybdenum, bismuth, and others. These metals are mostly found in the polymetal deposits of Altai and Dzungaria.

3.4 Uranium

Kazakhstan ranks first in the world in uranium mining and second in uranium reserves, trailing only Australia. According to the World Nuclear Association (WNA), Kazakhstan produced 21,819 tons of uranium in 2021, accounting for 45.14% of the world's production. As of 2019, the country's uranium reserves were estimated at 906,800 tons, or 15% of global reserves. Kazakhstan's uranium industry has experienced significant growth in recent years, driven by the increasing global demand for nuclear energy. Kazatomprom, Kazakhstan's national uranium company, plays a central role in the exploration, extraction, and processing of uranium ore.

3.5 Other minerals

In addition to the aforementioned resources, 99 elements from the Periodic Table are mined in Kazakhstan, including zinc, lead, chromium, nickel, manganese, and rare earth elements. These minerals contribute to various industrial sectors, including metallurgy, chemicals, and manufacturing, thereby supporting economic diversification and growth. The dynamics of metallurgical production, as provided by the Statistic Committee of the Republic of Kazakhstan, are presented in Table 1. Table 2 presents Kazakhstan's mineral resources and their percentage contribution to global reserves, as provided by Kazakh Invest.

4. Key indicators of industry performance

From January to December 2023, industrial products worth 46,401.7 billion tenge were produced, with 21,773.3 billion tenge (46.9% of the total volume) generated by the mining industry and 21,640.7 billion tenge (46.6%) by the manufacturing industry. From January to December 2023, Kazakhstan's industrial production index (IPI) amounted to 104.3%. Production growth was observed in the mining and quarrying industry by 4.6%, the manufacturing industry by 4.1%, the electricity, gas, steam, hot water, and air-conditioning supply by 1.8%, and water supply, waste collection, treatment, disposal, and pollution control activities by 1.9% (see Table 3).

Among the regions, the largest growth was recorded in Akmola, Atyrau, the North Kazakhstan, and Almaty.^[5]

According to the Project Engineering Group's analysis, the market volume of Kazakhstan's mining and metallurgical industry amounted to 6.5 billion US dollars over the 12 months of 2020, with OTP accounting for 58.3% and imported products for 41.7%.

Table 1. Dynamics of metallurgical production of the Republic of Kazakhstan for the representative period from 2010 – 2014 years.

Production	Year					2014 versus 2010, %
	2010	2011	2012	2013	2014	
Metallurgical industry						
Foundry pig iron	2893.9	3141.1	2707.0	2634.5	3184.8	110.1
Unrefined steel	4344.8	4811.5	3775.8	3503.4	4014.9	92.4
Ferroalloys	1701.8	1668.7	1724.0	1706.9	1715.1	100.8
Ferrous metal production						
Iron ore	50189.7	51742.0	52613.6	51688.6	51540.8	102.7
Manganese ore	3044.7	2963.0	2975.0	2850.5	2608.8	85.7
Chromium	5091.7	5059.0	5233.1	5255.1	5410.7	106.3
Chromium concentrate	3502.1	3670.0	3945.6	4192.7	4475.7	127.8
Nonferrous metal production						
Refined silver, t	549.0	646.7	958.5	958.3	983.7	179.2
Fine gold, t	13.5	16.7	21.1	23.2	26.9	199.3
Raw aluminum	1867.3	1919.2	1760.4	1840.2	1628.3	87.2
Raw lead	103.4	111.5	88.1	91.1	127.1	122.9
Raw zinc	318.9	319.8	319.8	320.2	325.0	101.9
Raw refined copper	323.4	338.5	367.2	352.1	294.8	91.2

Table 2. Mineral resources by elements represented in the Republic of Kazakhstan for 2019.

Mineral resource	Reserves (million tons)	Reserves, % of global total	World rank
Gold	0.349	2	15
Silver	0.195	5.7	2
Chrome ore	17	16.2	2
Coal	33.6	3.8	8
Copper	124	4.3	12
Iron ore	900	1.5	8
Lead	93	13.84	3
Molybdenum	51	9	4
Manganese	42	n/a	3
Uranium	56	12	2
Zinc	90	11	5

Table 3. Number of mining enterprises and productions and their contribution to market.

	Number of enterprises and productions	Volume of industrial production (goods, services), million tenge	Industrial production indices, in %
		Reporting period	Reporting period to the corresponding period of the previous year
Industry	2 435	46 401 716	104,3
Mining and quarrying	349	21 773 338	104,6
Coal mining	20	526 785	94,5
Crude petroleum and natural gas extraction	82	16 120 345	106,9
Crude petroleum extraction	80	15 860 637	106,8
Natural gas extraction	2	259 708	110,8
Mining of metallic ores	60	3 786 676	99,9
Iron ore mining	12	521 993	93,5
Mining of ores, except iron ores	48	3 264 683	101,0
Mining of other minerals	48	404 456	112,7
Mining support services	139	935 076	96,6

The industry is characterized by a high territorial concentration in three regions: Karaganda, East Kazakhstan, and Pavlodar. Karaganda's mining and metallurgical industry accounts for about 36% of the total production in Kazakhstan. The shares in East Kazakhstan and Pavlodar regions are 21% and 13%, respectively.

The Agency for Strategic Planning and Reforms of the Republic of Kazakhstan, in collaboration with the National Chamber of Entrepreneurs "Atameken", is focusing on developing the mining and metallurgical complex as part of the National Development Plan until 2029. Fig. 2 illustrates the contributions of different regions, highlighting the central and northeast regions as the main contributors in January 2021 (Fig. 2). The main priorities and key indicators of MMC have been identified (Fig. 3).^[6]

Overall, Kazakhstan plans production growth of MMC's sector around 40% from their current indicators in 2022nd. As key indicators the index of accumulated growth in the extraction of metals and other minerals and coverage of the geological and physical study of the territory were identified.

5. Mining Operations in Kazakhstan

Mining operations in Kazakhstan employ various techniques and methods tailored to the characteristics of specific mineral deposits. There are five main methods of mining: open pit mining, underground mining, in-situ leaching (ISL), placer mining, dredging, and hydraulic mining. Open-pit mining is the most commonly used method in Kazakhstan for extracting coal, iron ore, copper, and gold. This method involves extracting ore by removing the topsoil and rock that cover the mineral deposit, using heavy equipment such as excavators, haul trucks, and bulldozers.

Techniques used to extract minerals or ores from beneath the earth's surface are referred to as underground mining methods. Several techniques are employed in underground mining, including room-and-pillar mining, longwall mining, and sub-level caving. The choice of method depends on the geological conditions and the specific nature of the deposit. For example, the Karaganda Coal Mines include eight mines—Kostenko, Kuzembaeva, Saranskaya, Abayskaya, Kazakhstanskaya, Lenina, Shakhtinskaya, and Tentetskaya—

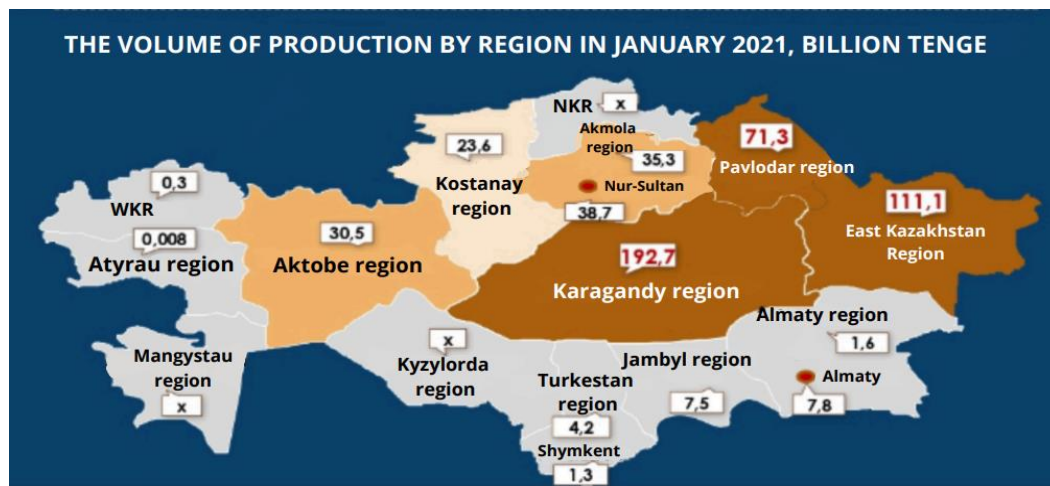


Fig. 2 The volume of production by region in January 2021 in billion tenge.

that employ underground coal mining techniques.^[7]

For soluble minerals like uranium, where physical excavation is not required, in-situ recovery (ISR) or in-situ leaching is applied. This method involves injecting a leaching solution, typically a weak acid or alkaline solution, into the mineral ore zone. The mineral dissolves into the solution,

which is then pumped to the surface for processing.

Kazakhstan holds the world's second-largest uranium resources, after Australia.^[8] Table 4 represents the segmentation of uranium production by major producer of uranium in Kazakhstan.

Table 4. Uranium segment production by Kazatomprom.^[8]

Indicator	Unit	2021	2022	Change, %
Production volume of U ₃ O ₈ (100% basis)	tU	21,819	21,227	3
Production volume of U ₃ O ₈ (attributable basis)	tU	11,858	11,373	4
U ₃ O ₈ sales volume (consolidated)	tU	16,526	16,358	1
Including KAP U ₃ O ₈ sales volume	tU	13,586	13,572	0
Group inventory of finished goods (U ₃ O ₈)	tU	8,824	9,352	6
Including KAP inventory of finished goods (U ₃ O ₈)	tU	7,724	7,749	0
Group average realized price	KZT/kg	36,677	52,051	42
Group average realized price	USD/lb	33.11	43.44	31
KAP average realized price	USD/lb	32.33	42.50	31
Average weekly spot price	USD/lb	35.05	49.61	42
Average month-end spot price	USD/lb	35.28	49.81	41



Fig. 3 The National Development Plan of Metallurgical and Mining Industry until 2029.

The companies are working on making uranium production safer. In this regard, the ISL method is increasingly being used instead of open-pit and underground mining to minimize the amount of radioactive waste generated during uranium mining.^[9,10]

5.1 Placer mining

Placer mining is a cornerstone technique in Kazakhstan's gold production, particularly in regions with abundant alluvial deposits such as East Kazakhstan, Pavlodar, and North Kazakhstan. This method involves a streamlined process that unfolds in three key stages.

First, placer mining focuses on extracting minerals embedded within alluvial deposits. These deposits, typically found in riverbeds, streams, and beach sands, harbor a wealth of precious resources. In Kazakhstan, gold, tin, and other heavy minerals are extracted through this method, significantly contributing to the nation's mineral wealth.

The simplicity of placer mining is its operational backbone. Using rudimentary yet effective equipment such as sluice boxes, dredges, and shovels, miners extract mineral-laden material from the earth. Sluice boxes separate the desired minerals from sediment, while dredges efficiently excavate larger quantities from riverbeds. The humble shovel remains an indispensable tool for manual extraction.

Once the mineral-bearing material is obtained, the process of unlocking its true value begins. The raw material undergoes meticulous processing techniques, ultimately yielding valuable minerals. This process culminates in the recovery of valuable minerals, driving Kazakhstan's gold production forward and solidifying placer mining as an essential pillar of the nation's mineral extraction.

Placer mining operations in Kazakhstan can have significant environmental implications, as evidenced by various global studies on placer mining activities. Placer mining disturbs riverbeds and sediment, which can release toxic trace elements (TTE), such as heavy metals, into the environment.^[11] This process can accelerate the natural release of elements like mercury into soils and rivers, impacting ecosystems.^[12] Additionally, placer mining can alter riverbed morphology by removing flora and fertile topsoil, which affects the overall ecosystem.^[13]

The impacts of placer mining extend beyond the immediate environment, affecting water quality and aquatic life downstream.^[14] Placer mining activities can redistribute deposits, leading to gold extraction in various regions.^[15] Environmental monitoring and assessment are crucial for understanding and mitigating the impacts of placer mining. Studies highlight the importance of monitoring ecosystems affected by placer mining to prevent further pollution and damage.^[16]

In Kazakhstan, where the mining industry plays a significant role, it is essential to consider the environmental consequences of placer mining. The country's rich mineral resources, including Ti-Zr placers and weathering crusts, pose

significant environmental management challenges.^[17] The choice of mining techniques, such as open-pit mining, can create environmental risks like pollution, habitat loss, and community impacts.^[18] Therefore, implementing sustainable practices and rigorous environmental monitoring is crucial to minimizing the negative effects of placer mining in Kazakhstan.

5.2 Dredging

Dredging operations in Kazakhstan involve the extraction of minerals through underwater excavation techniques. These operations often require large volumes of water, leading to sustainability challenges, especially in water-stressed regions like Kazakhstan.^[19] The safety and stability of these mining activities are crucial, as highlighted in studies assessing the safety factors associated with dredging and quarry mining techniques.^[20] Additionally, the environmental impacts of dredging, such as sediment removal and its effects on river systems, have been studied globally, emphasizing the need for proper monitoring and assessment.^[21]

In Kazakhstan, where uranium mining is significant, studies have focused on the radiological impact of mining activities on the population and the environment, highlighting the importance of environmental monitoring and assessment.^[22] Furthermore, the economic sustainability of mining in Kazakhstan has been researched, focusing on labor productivity and resource management to counteract depletion and rising costs.

Collaboration between universities, the state, and mining enterprises in Kazakhstan has been explored to enhance the mining and metallurgical complex, showcasing the importance of partnerships in advancing the industry.^[23] Moreover, the health effects of radon and uranium on Kazakhstan's population have been studied, emphasizing the need for proper conservation and management of uranium deposits.

5.3 Analysis of the distribution of mining activities across different regions of the country

To analyze the distribution of mining activities across different regions of Kazakhstan, it is essential to consider various factors that influence the spatial patterns of mining operations. The industry is characterised by a high territorial concentration in three regions: Karaganda, East Kazakhstan, and Pavlodar. The mining and metallurgical industry in Karaganda accounts for approximately 37.5% of Kazakhstan's total production. The shares in East Kazakhstan and Pavlodar are 19% and 14.9%, respectively illustrated in Fig. 4.

Copper deposits are primarily concentrated in Eastern and Central Kazakhstan. Copper reserves prepared for exploitation are expected to sustain mining operations for 10-12 years. The raw material base in Rudny Altai is gradually depleting, with no reserve deposits remaining at the active mining enterprises. However, Central, Eastern, and Southern Kazakhstan present potential opportunities for developing the mineral resource

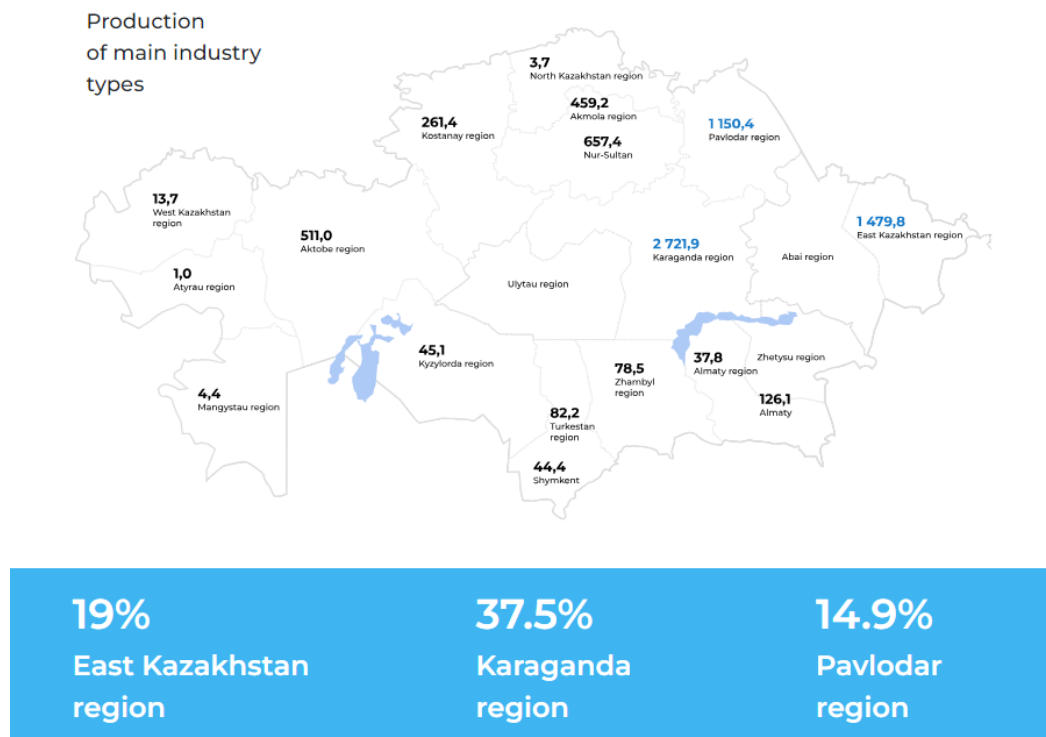


Fig. 4 Outputs of mining and metallurgical industry by regions in presents of total production.

base of the copper ore industry. Lead-zinc production is concentrated in East Kazakhstan. In the Ridder mining region, the main suppliers of raw materials are the Ridder-Sokolny mine and Chekmar, which, despite having large reserves, have low concentrations of useful components (Pb: 0.48-0.8%; Zn: 1.18-2.17%) (Fig. 5).

The Zyryanovsky mining region contains five deposits. The reserves of the previously exploited Grekhovskoye

deposit are classified as off-balance. The only industrial facility is the Maleyevskoye deposit, whose reserves are expected to sustain mining operations until 2030.^[24]

Studies on the socio-economic impacts of mining activities across regions can provide insights into the inequalities and challenges faced by communities in these areas.^[23] Additionally, research on the environmental consequences of mining, such as the health effects of radon and uranium

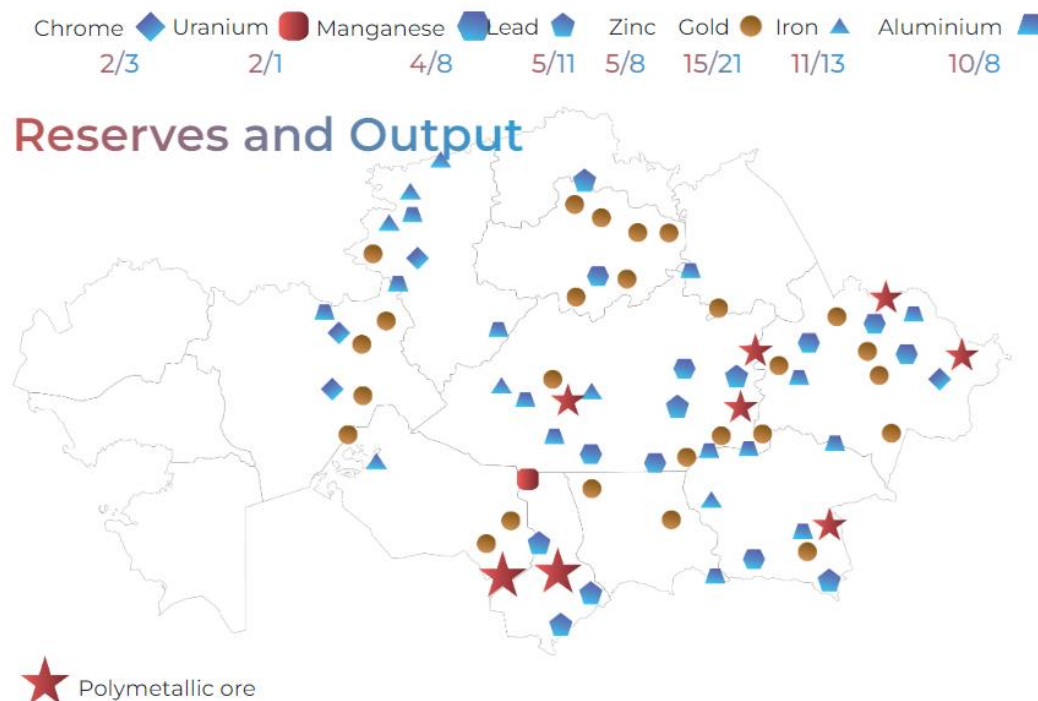


Fig. 5 Reserves and output of ores across different regions of Kazakhstan.

exposure, highlights the importance of understanding the regional implications of mining operations. Furthermore, studies on the economic sustainability of regional development and the impact of human capital on economic growth can shed light on the broader context of mining activities in Kazakhstan.^[25]

5.4 Discussion of the environmental and social impacts of mining activities

Mining activities have significant environmental and social impacts that must be carefully managed to ensure sustainable development. Previous reviews have mostly concentrated on the dynamics of the MMC' industry,^[26] experience of other countries compared to Kazakhstan in mining and metallurgy,^[27] as well as ecology and non-compliance with environmental standards.^[28,29] The concentration of coal, non-ferrous and ferrous metallurgy enterprises in Kazakhstan has led to a significant level of pollution of all components of the natural environment. As a result, Kazakhstan has traditionally been among the regions with the highest proportion for the emission of pollutants into the atmosphere and the polluted wastewater discharge. Nevertheless, the most important components that determine the current general environmental situation are the real state of the air and water basins, and the consumption of water resources. Due to the rapid development of the mining and metallurgical industry, air pollution has turned into one of the most difficult environmental problems of our time in recent decades. Despite the fact that Kazakhstan is not the main supplier of pollutants to the atmosphere compared to industrialized countries, according to the Ministry of Environment and Water Resources of the Republic of Kazakhstan, at the end of the 20th century the level of air pollution in cities remained comparatively high by international standards.

The cumulative water impacts of mining in Kazakhstan have been substantial due to the increased number of mining companies over the last decade. Environmental assessments of coal mining systems have identified potential impacts such as acid water drainage, surface subsidence, and alterations of groundwater aquifers. The long history of solid mineral development in Kazakhstan has led to the use of outdated mining technologies, resulting in significant energy and water resource consumption and posing risks to the natural environment. On the other hand, the mining operations in Kazakhstan have been associated with environmental contamination by toxic trace elements (TTE) such as heavy metals, leading to serious ecological problems near industrial complexes and mining sites.^[30] The release of these elements into the environment can have detrimental effects on ecosystems, water quality, and human health.

Establishing sustainable mining operations is crucial to address the impacts of resource depletion and environmental degradation caused by mining activities. Environmental Impact Assessments (EIAs) play a key role in evaluating the negative impacts of mining activities on the environment,

including pollution of air, water, soil, and subsoil. The exploitation phase of mining operations, involving activities like excavation, transportation, blasting, and ore processing, contributes to climate change, particulate matter formation, and land destruction.^[31]

The health effects of radon and uranium exposure on the population of Kazakhstan highlight the significant impact of radioactive contamination on the environment and human health.^[32] Sustainable development in the mining industry is essential to address corporate perspectives and ensure responsible mining practices that consider environmental and social factors.^[33] The decline in ore grades necessitates increased mining activities, leading to higher waste generation, greenhouse gas emissions, and social pressures on mining operations.

In Kazakhstan, the mining and metallurgical industry, a significant sector of the economy, faces environmental challenges due to increasing levels of pollution. The country's specialization in fossil fuel exports and coal-based power generation contributes to global greenhouse gas emissions, emphasizing the need for sustainable practices in the energy and mining sectors.^[34] The industrial progress in mining and metallurgy has led to a rise in environmental pollution, necessitating solutions to mitigate the negative impacts.

The environmental problems in Kazakhstan, including air pollution, greenhouse gas emissions, and industrial production impacts, require urgent attention to prevent further ecological degradation.^[35] The country's transition to sustainable development involves preserving natural systems, implementing environmental concepts, and addressing socio-economic and demographic aspects. The assessment of sustainability in mining operations is essential to minimize environmental impacts and promote responsible resource management.

6. Metallurgical processing facilities

Kazakhstan is home to numerous metallurgical plants and facilities that play a significant role in the country's industrial output and economy. These facilities are essential for processing various metals and minerals extracted from Kazakhstan's abundant natural resources. Here's an overview of some critical metallurgical plants and facilities in the country.

a) Karaganda metallurgical complex (Karmet)

Karmet is one of the largest metallurgical complexes in Kazakhstan, located in the Karaganda region. Specializing in the production of steel and rolled products such as rebar, wire rod, and structural steel, the complex encompasses blast furnaces, steelmaking converters, rolling mills, and other processing units.

b) Balkhash copper smelter

Situated near Balkhash in the East Kazakhstan region, the Balkhash Copper Smelter is an important facility for

processing copper concentrates. The smelter produces copper cathodes, rods, and other copper products for both domestic and international markets.

c) Pavlodar aluminum smelter

The Pavlodar Aluminum Smelter, located in the Pavlodar region of Kazakhstan, is one of the largest aluminum smelters in the country. The smelter specializes in producing primary aluminum ingots, aluminum alloys, and various other aluminum products for use in different industries. Equipped with modern technology, the smelter has efficient facilities for aluminum production.

d) ArcelorMittal Temirtau

ArcelorMittal Temirtau is the largest integrated steel plant in Kazakhstan, located in the Karaganda region. It manufactures various steel products, including hot-rolled and cold-rolled coils, wire rods, and sections. The plant also encompasses facilities for iron ore mining and processing.

e) Eurasian Resources Group (ERG) metallurgical plants

ERG operates multiple metallurgical plants in Kazakhstan, specializing in the production of ferroalloys. These facilities manufacture ferrochrome, ferrosilicon, and manganese alloys used in steelmaking and other industries, and are located in various regions including Aktobe, Karaganda, and Pavlodar.

f) Kazzinc integrated metallurgical complex

Kazzinc is a top zinc producer in Kazakhstan, with an integrated metallurgical complex in the East Kazakhstan region. This complex includes mining, concentrating, and metallurgical facilities for producing zinc, lead, and other non-ferrous metals. Within Kazakhstan, Kazzinc's metallurgical operations consist of zinc and lead smelters, as well as facilities for refining and processing zinc and lead concentrates. These metallurgical plants and facilities, under the leadership of Kazzinc, play a crucial role in adding value to Kazakhstan's natural resources. They demonstrate the country's significant capabilities in processing metals and minerals, contributing to industrial development, economic growth, and export revenues. Moreover, they support downstream industries and value chains, thereby enhancing the country's economy.

g) Aktogay copper mine

The Aktogay copper mine, also operated by KAZ Minerals, is another significant mining project in Kazakhstan. Located in the East Region of Kazakhstan, Aktogay is one of the largest open-pit copper mines in the world, with proven and probable reserves of over 2.5 billion tonnes of ore. The mine commenced production in 2017 and has since ramped up to full capacity, producing over 100,000 tonnes of copper cathode annually. The mine, located in the East Region of Kazakhstan, is recognized for its substantial copper reserves and high-quality ore deposits. The Aktogay mine utilizes

modern mining techniques and processing methods to extract and refine copper, contributing significantly to the country's copper production capacity.^[36] The project's success highlights Kazakhstan's potential as a key player in the global copper market and underscores the importance of sustainable mining practices in the region. These case studies demonstrate the successful implementation of mining and metallurgical projects in Kazakhstan, showcasing the country's ability to attract foreign investment, adopt advanced technologies, and drive economic growth through the mining sector. By leveraging its rich mineral resources and fostering strategic partnerships with international mining companies, Kazakhstan has positioned itself as a key player in the global mining industry. The success of projects like the Bozshakol and Aktogay Copper Mines underscores the country's commitment to sustainable resource development, environmental stewardship, and socio-economic progress in the mining sector. These case studies demonstrate Kazakhstan's potential for developing large-scale, successful mining and metallurgical projects that contribute to economic growth, infrastructure development, and job creation in the country. They also highlight the importance of strategic investment, technological innovation, and responsible resource management in ensuring the success and sustainability of such projects.^[36]

7. Exploration and prospecting

The extraction and processing of minerals involve a series of complex processes to recover valuable minerals from the Earth's crust and convert them into usable products. Fig. 6 gives a general description of the critical processes involved.

The mining process starts with exploration and prospecting activities to find areas with potential mineral deposits. Geological surveys, remote sensing techniques, and geophysical surveys are used to identify mineral-rich zones and assess their economic viability. Once potential areas are found, drilling is carried out to obtain core samples and collect geological data. The core samples are then analyzed to determine the mineral composition, grade, and extent of the deposit. Mining includes extracting mineral resources from the earth's crust using various methods and techniques.

Standard mining methods include open-pit mining, underground mining, and placer mining, depending on the type and location of the deposit. Extraction techniques may involve blasting, drilling, excavation, and transporting ore to the surface for processing. After extraction, the mined ore is transported to a processing plant, where it undergoes crushing and grinding to reduce the size of the ore particles. Crushing breaks the ore into smaller pieces using crushers, while grinding further reduces the particle size through milling processes such as ball mills and rod mills. Once crushed and ground, the ore undergoes mineral separation and concentration to separate the valuable minerals from the waste material. Techniques such as gravity separation, flotation, magnetic separation, and leaching are used to concentrate the

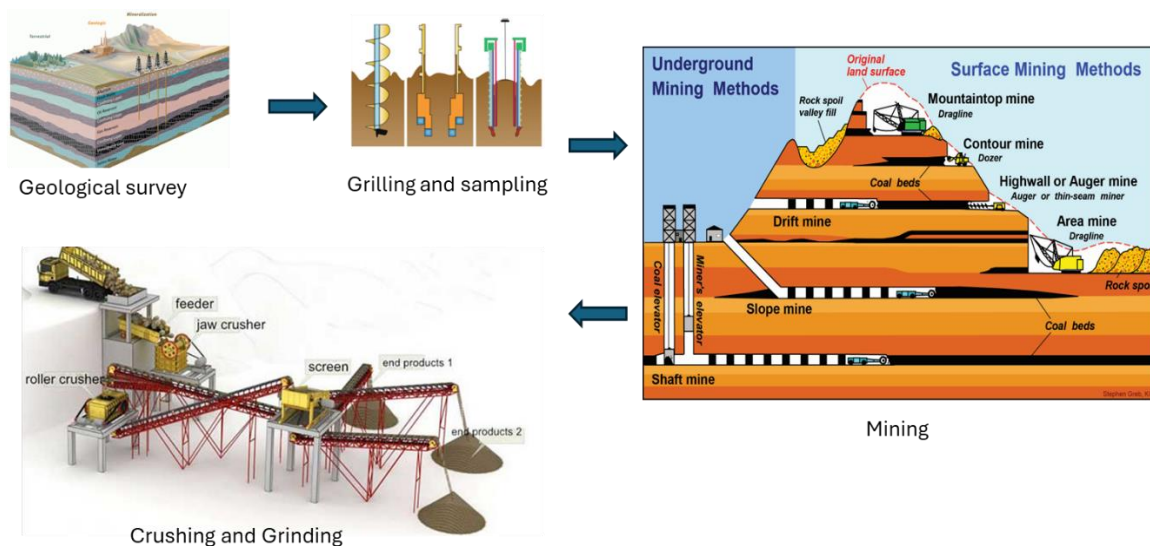


Fig. 6 Stages of mining.

desired minerals into a concentrated form.

In some cases, concentrated minerals undergo smelting and refining processes to extract the metal or produce metal alloys. Smelting involves heating the concentrated ore in a furnace with reducing agents to remove impurities and extract the metal. Refining processes purify the metal through electrolysis, precipitation, or chemical reactions to achieve desired purity and quality standards. The extracted metals and minerals may undergo further processing and value addition to produce intermediate products or finished goods.

This additional processing may involve casting, forging, rolling, extrusion, and other forming processes to shape metals into desired products such as bars, sheets, tubes, and components. Environmental management measures are implemented throughout the extraction and processing stages to minimize impacts on air, water, and land resources. Rehabilitation and reclamation efforts aim to restore mined areas to a stable and environmentally sustainable condition, including revegetation, soil stabilization, and water management. These processes vary depending on the type of mineral deposit, its physical and chemical properties, and the desired end products. Effective management of these processes is essential to ensure sustainable resource utilization, minimize environmental impacts, and maximize economic benefits.^[37]

8. Economic importance and contribution to GDP

The mining and metallurgical complex play a crucial role in Kazakhstan's economy, significantly impacting its Gross Domestic Product (GDP) and overall economic performance. Kazakhstan, being rich in mineral resources such as copper, gold, iron, lead, titanium, zinc, and uranium, has built a substantial part of its economy around mining and heavy industry. The mining sector, along with metal mining, coal mining, and petroleum extraction, contributes significantly to Kazakhstan's GDP, with reports indicating that over a third of the country's GDP is generated by mining and metallurgy.^[38]

Moreover, the energy sector, including oil and gas, is a fundamental component of Kazakhstan's economy, further underlining the economic significance of the mining and metallurgical complex.^[39]

The impact of the mining and metallurgical industry extends beyond just economic contributions. Large mining and metallurgical enterprises in Kazakhstan are often located in monotonowns, exerting a significant influence on the socio-economic development of these regions.^[40] Additionally, the mining industry in Kazakhstan has been noted to contribute substantially to the country's total export earnings, further emphasizing its economic importance.^[41] The sector's influence on the macroeconomic performance of Kazakhstan is profound, with the Minister of Energy highlighting uranium mining as one of the most developed areas in the country's nuclear industry.^[42]

Furthermore, the multiplier effect of the mining sector's development on related industries and sectors of the economy is crucial. The level of processing of mining products in Kazakhstan is determined by this multiplier effect, with a direct impact on the country's socio-economic development and global competitiveness.^[43] The mining industry's role in the observed change in GDP energy intensity is significant, indicating its influence on energy consumption patterns and economic dynamics.^[44] Additionally, the agriculture and livestock sector, which is one of Kazakhstan's major export items, follows closely behind the energy and mining sectors in terms of economic contribution.^[45]

Despite the economic benefits derived from the mining and metallurgical complex, there are also environmental considerations to be addressed. The evaluation of environmental contamination by toxic trace elements in Kazakhstan has raised concerns about the environmental impact of mining activities.^[46] Studies on the state of vegetation cover of recultivated dumps of uranium deposits in Northern Kazakhstan highlight the need for sustainable practices in mining to mitigate environmental degradation.^[47]

Moreover, the adoption of green building assessment systems in Kazakhstan underscores the importance of sustainable development practices within the mining sector to minimize environmental impact.

In conclusion, the mining and metallurgical complex significantly contribute to Kazakhstan's GDP and overall economic development. The sector's economic importance is evident through its substantial share of the country's GDP, export earnings, and influence on related industries. However, it is essential for Kazakhstan to balance economic growth with environmental sustainability to ensure the long-term viability of the mining industry. Implementing sustainable practices, investing in green technologies, and addressing environmental concerns are crucial steps towards maximizing the economic benefits of the mining and metallurgical complex while minimizing its environmental footprint.

9. Government policies and regulations

Government policies, regulations, and incentives play a crucial role in shaping the mining and metallurgical sector in Kazakhstan. The country's mining and metallurgical industry, which contributes significantly to its GDP, is subject to various institutional measures and regulatory frameworks aimed at promoting sustainable development, energy efficiency, and environmental protection.^[48] These measures are essential for accelerating the transition of industrial enterprises towards renewable energy sources and enhancing energy efficiency in the sector.

Regarding tax policies and incentives, governments in mining regions, including Kazakhstan, are encouraged to focus on improving socio-economic infrastructure, providing geological information, and ensuring political and economic stability to attract foreign direct investment in the mining sector.^[49] By enhancing infrastructure quality and promoting stability, governments can create an attractive investment climate for mining companies, thereby fostering economic growth and development in the sector.

Kazakhstan has implemented policies aimed at maximizing the mining sector's contribution to the country's GDP. These policies are designed to support the growth and development of the mining and metallurgical industry, recognizing its significance as a key sector in the economy.^[50] By focusing on policies that enhance the sector's productivity and efficiency, Kazakhstan aims to leverage the mining industry's potential to drive economic growth and prosperity. In terms of governance and regulatory performance, clear and consistent rules and regulations are crucial for attracting foreign mining investments. A stable government policy towards the mining sector, efficient regulatory capacity, and clear guidelines for regulators can reduce uncertainty and risks for foreign investors, thereby promoting investment in the sector.^[51] By ensuring regulatory stability and efficiency, Kazakhstan can create a conducive environment for foreign mining investments and industry growth.

Furthermore, environmental considerations are paramount

in the mining and metallurgical sector. As the industry continues to expand, the level of environmental pollution is increasing, necessitating the implementation of environmental protection measures and sustainable practices.^[52] Strengthening resource and energy-saving policies, as well as addressing environmental challenges, are essential for ensuring the long-term sustainability of the mining and metallurgical complex in Kazakhstan.^[53]

In conclusion, government policies, regulations, and incentives have a significant impact on the mining and metallurgical sector in Kazakhstan. By implementing measures to promote sustainable development, energy efficiency, and environmental protection, Kazakhstan can harness the full potential of its mining industry for economic growth while ensuring long-term sustainability and responsible resource management.

10. Investment and foreign participation

To assess foreign investment trends and involvement in Kazakhstan's mining and metallurgical sector, it is essential to consider insights from relevant studies. While there is a scarcity of direct references specifically addressing foreign investment trends in Kazakhstan's mining sector, insights from related research can provide valuable perspectives on foreign investment patterns, impacts on local communities, and the role of multinational corporations in the mining industry.

Studies on the expropriation of foreign direct investments (FDI) in various sectors, including mining and petroleum, raise concerns over foreign dependency and sectoral patterns. The concentration of foreign ownership in the mining sector can impact economic stability and national sovereignty, underscoring the importance of a balanced approach to foreign investment.^[54] Additionally, research on the determinants of FDI in the mining sector in Zimbabwe emphasizes the significance of understanding the motivations driving corporate investments in the sector.^[55]

Insights from studies on the impacts of foreign mining investments on land use systems, livelihoods, and political stability in regions like Ghana and Africa shed light on the environmental and social costs associated with foreign investments in the mining sector.^[56,57] Understanding labor dynamics, such as labor militancy, segmentation, and social inequality in the extractive sector, as observed in Kazakhstan's oilfields and South Africa's platinum mines, provides insights into foreign ownership and labor relations in the mining industry.

Moreover, research on the role of multinational corporations in foreign direct investments, political risks, and globalization strategies in the mining sector offers valuable perspectives on the dynamics of foreign investments in the industry.^[58,59] The interplay between foreign investment, government policies, and environmental, social, and governance (ESG) risk ratings in mining enterprises underscores the importance of sustainable practices and digital transformation in the sector.^[60]

In conclusion, although direct references specific to foreign investment trends in Kazakhstan's mining sector are limited, insights from related studies on foreign investments, expropriation patterns, and multinational corporation strategies provide valuable perspectives on the dynamics of foreign participation in the mining and metallurgical sector. Understanding the determinants of foreign investments, their impacts on local communities, and the implications for economic development and sustainability is crucial for policymakers and industry stakeholders in Kazakhstan.

11. Challenges and opportunities

Kazakhstan's mining and metallurgical complex faces several key challenges that affect its operations, sustainability and competitiveness. Kazakhstan, with its vast territory and underdeveloped infrastructure, which in some regions actually needs to be rebuilt, is exclusively interested in the inflow of foreign direct investment. The importance of these investments also lies in creating conditions for human development. There are barriers for enterprises in Kazakhstan in the form of unsatisfactory condition of roads and railways, cargo aviation, transit hubs, electric networks; actions of authorities restricting the development of entrepreneurship. The unsatisfactory condition of roads and railways makes it difficult to transport raw materials and finished products, increasing logistics time and costs.^[61] Cargo aviation and transit hubs are also underdeveloped, which limits opportunities for effective international trade. Problems with electrical networks and their unreliability can lead to production disruptions and reduced productivity. Many enterprises work with outdated and worn-out basic production assets, which reduces their efficiency and increases the amount of harmful emissions.^[62]

The high level of environmental pollution caused by the activities of mining and metallurgical enterprises leads to a deterioration of the environmental situation and requires significant costs for environmental protection measures. As a result of anthropogenic loads, the natural ability of the natural environment to ensure the future economic and social development of the country has been disrupted in almost the entire territory of Kazakhstan.^[63] Most enterprises of the processing and energy complexes have imperfect technology, morally and physically worn-out basic production assets, which contributes to an increase in the number of harmful emissions. In the early 90s, about 6 million tons of pollutants were released into the atmosphere annually (50% - thermal energy, 20%-ferrous metallurgy, 13% - non-ferrous metallurgy, 4% - chemistry and petrochemistry).^[64] Most areas of high air pollution coincide with places of concentrated human settlement. Until 2024, the volume of toxic waste generation in Kazakhstan amounted to about 84.4 million tons annually. These wastes are mainly generated in non-ferrous metallurgy, which accounts for about 63% of the total volume. The main regions where significant toxic waste generation is observed include Karaganda, East Kazakhstan, Kostanay and Pavlodar

regions.

In recent years, there has been an increase in the amount of recyclable waste. Since 2016, the share of solid waste recycling has increased from 2.6% to 11.5%, and the share of industrial waste recycling has increased from 26.8% to 32.2%. This progress also points to improved waste recycling infrastructure and more efficient use of resources.^[65]

12. Future outlook and prospects

Mining is likely to continue to grow in Kazakhstan, due to the ongoing exploration and development of deposits, as well as investments in the modernization and expansion of existing mining and metallurgical enterprises. The growing demand for commodities such as copper, gold, uranium and rare earths, driven by industrialization, urbanization and technological innovation, will contribute to production growth in the long term.^[66]

The mining and metallurgical industry of Kazakhstan has many favorable factors that ensure its successful long-term development. Among them, the following justifications can be distinguished:

- The special geographical location of enterprises and their access to world markets (regional proximity to Southeast Asia and Russia, large exporters have the opportunity to have an extensive network of markets in Europe and the USA)
- Availability of energy resources and its own raw material base, including ferrous and non-ferrous metal ores, coking coals, rare, rare earth, radioactive and precious metals.
- The presence of a production base and a developed infrastructure of enterprises with specialized research centers and factory laboratories;
- Attractiveness for external investments in the industry;
- The existing raw material orientation of the economy without processing.

When analyzing the prospects for the development of the mining and metallurgical complex of Kazakhstan, below are recommended areas to improve in order to proceed in enhancing MMC:

The need to strengthen the resource and energy conservation policy. Obviously, to preserve solid minerals for future generations, today, it is necessary to use the latest technologies for the most complete extraction of useful raw materials with the lowest energy consumption.^[67]

The development of a waste recycling system and increased resource conservation, as well as the integrated processing of non-ferrous, precious and rare metals are key factors for ensuring production efficiency and improving the environmental situation in areas of concentration of mining and metallurgical enterprises. An illustrative example is the Ust-Kamenogorsk lead-zinc Combine, where an industrial line for processing slags of current production and old dumps was put into operation.

Introducing such technologies allows not only the reduction of waste but also the return of significant amounts of valuable materials to production. This helps to increase

economic efficiency and reduce the negative impact on the environment. Examples of such projects highlight the importance of investing in innovative technologies and sustainable development in the mining and metallurgical industry.^[68]

Special attention is recommended to developing high-tech industries with high economic potential. In particular, this refers to an increase in the production of rare and rare earth metals, which are currently produced at the enterprises of Kazzinc LLP, Kazakhmys Corporation LLP, Ulba Metallurgical Plant JSC. The main task is to increase the depth of conversion and purity of the metals obtained.^[69]

The most important task remains to attract leading multinational companies to the mining and metallurgical industry.

13. Case studies and best practices

Successful mining and metallurgical projects in Kazakhstan serve as exemplars of effective project management, sustainable practices, and positive socio-economic impacts. One notable case study is the "Landfill Mining" project, which focused on metals recovery and waste management, showcasing a successful initiative in the waste sector.^[70] This project demonstrated the potential for resource recovery, environmental remediation, and circular economy principles in Kazakhstan's mining industry.

Another significant case study is the "Ereymtau Wind Power Plant (WPP)" project, which exemplifies the country's commitment to renewable energy and sustainable development.^[71] By harnessing wind power in the Northern region of Kazakhstan, this project showcases the successful integration of clean energy solutions into the country's energy mix, contributing to environmental sustainability and reducing greenhouse gas emissions.

Furthermore, the "Smart Aqkol" project serves as a pioneering example of smart city development in Kazakhstan, highlighting the country's efforts towards modernization and digital transformation. This project demonstrates the successful implementation of smart technologies, urban planning strategies, and sustainable infrastructure development, fostering innovation and enhancing the quality of life for residents.

In the mining sector, the "Green Energy Project's Efficiency" study provides insights into the cross-industry evaluation of green energy initiatives, emphasizing the importance of project management methods in enhancing efficiency and success rates.^[72] This case study underscores the significance of integrating sustainable practices and renewable energy solutions into mining and metallurgical projects to drive environmental stewardship and long-term viability.

Moreover, the "Reconciling Climate Change Leadership with Resource Nationalism" case study sheds light on Kazakhstan's approach to balancing climate commitments with resource extraction activities.^[73] This study highlights the complexities of navigating climate change imperatives,

resource nationalism, and regional vulnerabilities, offering valuable lessons for sustainable resource management and policy development in the mining sector.

Overall, these case studies demonstrate Kazakhstan's progress in implementing successful mining and metallurgical projects that prioritize environmental responsibility, innovation, and socio-economic development. By leveraging best practices, sustainable technologies, and strategic partnerships, Kazakhstan's mining industry continues to evolve towards a more sustainable and resilient future.

14. Conclusion

Kazakhstan's mining and metallurgical sector has enormous room to grow and expand economically. Kazakhstan is positioned as a major player in the global market because of the industry's wealth of mineral resources, which encourages government policies and foreign investments. Nonetheless, it is imperative to tackle obstacles, including restricted infrastructure, ecological worries, and intricate regulations. The sector's success going forward will depend on embracing technology breakthroughs, encouraging sustainable practices, and increasing stakeholder engagement. By concentrating on these sectors, Kazakhstan can guarantee the mining and metallurgical sector's sustainable growth, promoting the country's economic prosperity and raising the standard of living for its people. A balanced strategy that incorporates economic, environmental, and social factors is necessary for the industry's survival. Infrastructure and technological investments are essential to overcoming present challenges.

Stricter environmental laws and environmentally friendly mining techniques will also lessen the harm done to communities and ecosystems. Cooperation between the government, industry players, and local populations is essential for the mining industry to thrive. This entails establishing just and transparent regulatory frameworks and offering instruction and training to develop a workforce with the necessary skills. Since foreign investments provide capital, knowledge, and technology to spur innovation and industry growth, their role in the industry must be balanced. The evaluation emphasises how crucial it is to expand downstream processing capabilities and investigate new markets to diversify the sector. By diversifying, the industry will become more resilient to changes in the global market and generate more revenue.

In conclusion, Kazakhstan's mining and metallurgical sector is at a turning point. By tackling the current issues and seizing the opportunity, the industry may grow sustainably and significantly contribute to the nation's development. The way forward calls for cooperation, thoughtful preparation, and a dedication to sustainability and creativity. Kazakhstan's mining and metallurgical sector has the potential to grow and be a pillar of the country's economy for many years to come if the right policies are put in place. The findings of the study could have significant implications for assessing the future risks and opportunities in the mining and metallurgical

industry. They can also offer initial insights for stakeholders and foreign investors. To ensure the sustainable development of the mining and metallurgical sector, future efforts should focus on implementing appropriate policies, effective waste management, integrating high-tech solutions, and adopting best practices.

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Conflict of Interest

There is no conflict of interest.

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