DEVELOPING CHROMITE DEPOSITS IN THE MOUNTAINS OF AZERBAIJAN USING MOBILE PLANTS AND ENSURING ENVIRONMENTALLY AND ECONOMICALLY SUSTAINABLE MINING

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Abstract

This study focuses on developing chromite deposits in Azerbaijan's mountain regions using mobile processing plants to ensure environmentally safe mining. The main objective is to process high-quality chromite ore directly at the mine. This reduces transport and logistics costs, lowers environmental impact and brings economic and social benefits to local communities. The research analyses the technical and economic performance of mobile plants, including their energy use, carbon emissions, water usage and recycling systems. The results show that using mobile plants can reduce energy consumption and the carbon footprint. At the same time, water reuse and effective waste management help to protect the environment. The study also examines how well these activities align with Azerbaijan's laws and international standards. It makes recommendations for improving the legal and regulatory framework for mobile plant use. In conclusion, mobile processing plants can support the growth of Azerbaijan's metallurgical industry, protect the environment and boost the local economy in mining areas.

Keywords: Kelbajar-Lachin zone, chromite, platinum group elements, mineralization, geological sections, petrology, geochemistry

I. Introduction

Chromite minerals hold strategic importance for industry, as they are the primary raw material for the production of ferrochrome and stainless steel. The growth of global industrial demand and the need for efficient use of raw materials require a more sustainable and modern approach to the development of these mineral resources. This is especially relevant for chromitite deposits located in hard-to-reach mountainous regions with poorly developed infrastructure, where exploitation by traditional stationary mining and processing plants faces technical and economic difficulties. The mountainous regions of the Republic of Azerbaijan — in particular, the Kelbajar- Lachin geological zone — are rich in high-quality chromite minerals. However, the complex terrain and underdeveloped mining infrastructure significantly hinder the industrial development of these deposits. In this context, the use of mobile (portable) beneficiation plants serves as an alternative and promising technology. Mobile plants can be quickly installed and provide on-site raw material processing, reducing transportation costs and minimizing the impact on the natural environment. This study evaluates the possibilities for developing Azerbaijan's chromitite resources using mobile technologies and justifies transforming this approach into an environmentally 2 sustainable exploitation model. The article analyzes the technical advantages of mobile plants, ways to reduce environmental risks, and techno-economic indicators. In addition, the study references international experience and demonstrates the effectiveness of applying these technologies in the mountainous regions of Azerbaijan.

II. Study area and geological conditions

The result of predicting the risk of a certain event is to determine when, where and with what (what) characteristics the event will occur. In general, non-parametric methods are often used in risk forecasting, such as the least squares method, which evaluates the accuracy of the forecast.

III. Engage experts

The mountainous regions in the southwestern part of the Republic of Azerbaijan — particularly the Kelbajar-Lachin geological zone — are characterized by the widespread occurrence of ophiolitic complexes rich in chromitites. These complexes were mainly formed within Mesozoic ultrabasic rocks of both mantle and crustal origin, including dunites, harzburgites, and serpentinites. Chromitite lenses in this zone are typically located in the central parts of dunite massifs and occur as natural bodies of varying size. The main deposits are concentrated in the areas of Gamishli, Karachinar, Khachikend, and Shekerchay (1.2.3). From a geological perspective, these territories belong to the Eastern Pontide–Kura–Araz ophiolite belt and include fragments of paleo-oceanic lithosphere complexes. Chromitite mineralization is mainly represented by aluminum-chromite type and, less frequently, by magnesium-chromite type. These minerals are considered to be high-quality industrial materials with Cr_2O_3 contents ranging from 40% to 54% and a low FeO/MgO ratio. The chemical composition of selected chromitite samples from the Kelbajar-Lachin zone was analyzed under laboratory conditions (Table 1), using X-ray fluorescence (XRF) and inductively coupled plasma mass spectrometry (ICP-MS) techniques.

Table 1: *Chemical composition of selected chromitite samples collected from the Kelbajar- Lachin zone*

Sample	Cr_2O_3 (%)	FeO (%)	MgO (%)	Al_2O_3 (%)	SiO_2 (%)
XLM-01	48.3	22.1	9.5	10.2	3.1
LM-02	50.5	20.8	8.9	11.0	2.5
XLM-03	46.7	24.2	10.1	9.8	3.4

As a result of geochemical analyses, it has been established that the quality characteristics of chromitites in these deposits meet international standards and, in most cases, can be used directly for ferrochrome production. The structure and mineralogy of the deposits indicate that they are suitable for industrial processing, particularly for primary beneficiation using mobile processing plants. In addition, minor concentrations of platinum group elements (PGE) — especially platinum (Pt), palladium (Pd), and gold (Au) — have been identified in several deposits, which provides an additional economic advantage for the integrated development of these sites. The locations of the studied areas, geological context, and sampling points are shown on the map (Fig. 1 and 2).

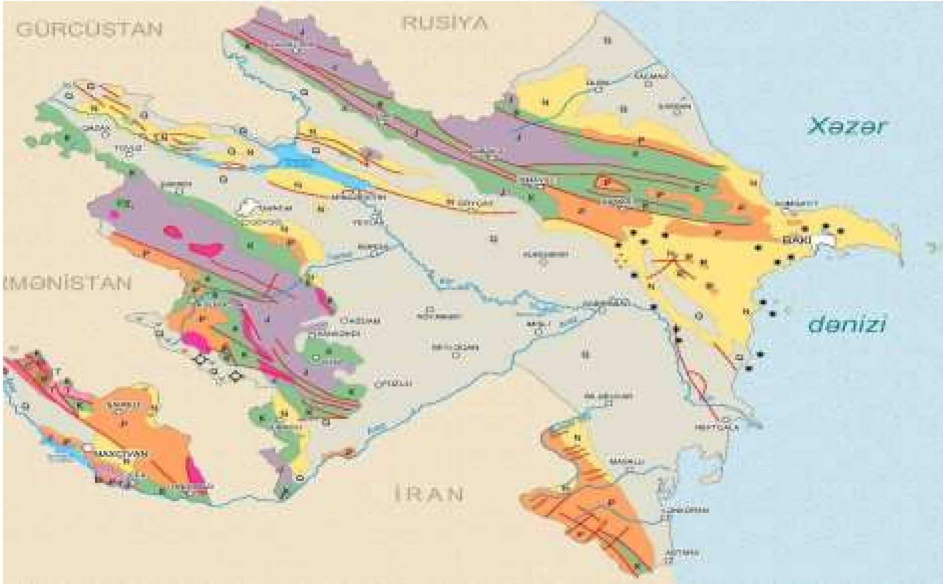

Figure 1: *Geological map of the republic of Azerbaijan*

To visualize the spatial distribution of chromite deposits, the geological context of the region, and the sampling points, a thematic geological map was developed. It highlights key elements, including:

- Ophiolite belts, marked by red structural lines on the geological map, indicating potential zones of chromite mineralization and deposits (Fig. 1);
- The main chromite deposits of the Kalbajar–Lachin zone (Kamishly, Karachinar, Shekerchai, Khachikend, etc.);
- Stratigraphic and lithological units, including ultramafic massifs and ophiolitic complexes;
- Coordinates of the sampling points at Kamishly, Shekerchai, and Khachikend (Fig. 2);
- Transport infrastructure elements and proposed sites for the deployment of mobile processing complexes, taking into account production efficiency and logistical accessibility.

The map serves as an important tool for analyzing geological and industrial conditions, as well as for the preliminary assessment of development prospects and the organization of chromite ore processing at specific sites.

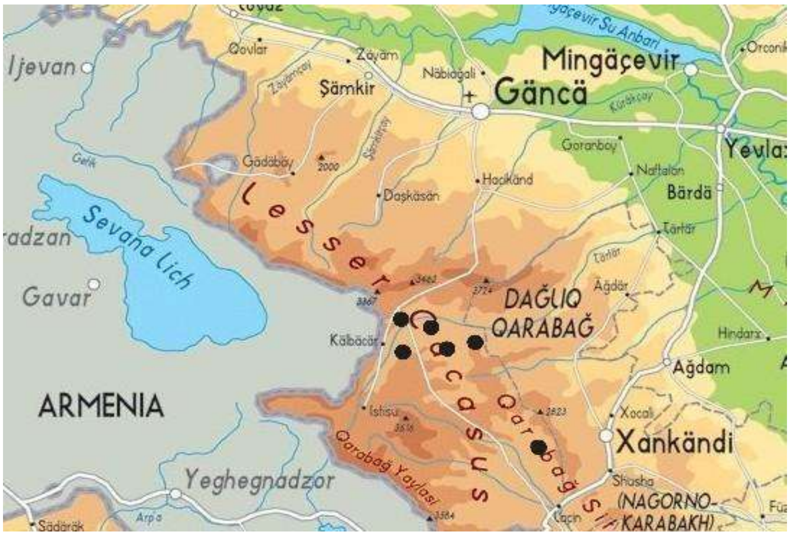

Figure 1: *Cordinates of sampling points*

To provide a comprehensive view of the geological and structural conditions, spatial distribution of chromite deposits, sampling points, and infrastructure potential, a geological map of the region was created. It highlights key elements, including chromite deposits (Gamishly, Karachinar, Shekerchai, Khachikend, and others), major geological structures (ultramafic massifs and ophiolite complexes), sampling points with coordinates, as well as potential sites for deploying mobile processing plants from a production perspective [4,5,6].

This map provides a schematic representation of the geological setting of the Kalbajar–Lachin zone, including geomorphological and infrastructure features. Chromite deposits in the region are mainly located within the ophiolitic complexes of the Lesser Caucasus. These formations, which represent remnants of ancient oceanic lithosphere, consist mainly of dunites, peridotites, and other ultramafic rocks, where chromite occurs in the form of lenses and veins. Two major groups are particularly distinguished (Table 2):

- The Goydarya Group (Kalbajar District) is characterized by lens-shaped bodies of chromite mineralization within dunites, with ore body thicknesses ranging from 0.5 to 15 meters and Cr_2O_3 content from 43.5% to 52.6%.
- The Ipek Group (Lachin District) is represented by lenses within hyperbasites, with Cr_2O_3 content ranging from 25.0% to 39.5% and ore body thicknesses from 0.5 to 5 meters.

The mineralogical composition of chromite ores includes the following major components:

- Chromite ($FeCr_2O_4$) – the primary ore mineral, with a high Cr_2O_3 content;
- Olivine ($(Mg,Fe)_2SiO_4$) – commonly associated with chromite, dominant in dunites;
- Pyroxenes (enstatite, diopside) – components of ultramafic rocks;
- Serpentine minerals – secondary phases indicating intense serpentinization of the rocks.

The combination of these minerals reflects the specific formation conditions of the chromite mineralization in the region.

Table 2: *Major chemical composition of chromite minerals in Azerbaijan.*

Component	Content (%)
Cr_2O_3	43,5–52,6
FeO	16,4
SiO_2	33,8
MgO	8,5
Al_2O_3	9,2
TiO_2	0,3
CaO	0,2

The chemical and mineralogical characteristics indicate a high industrial potential of chromite deposits in Azerbaijan (Table 3). The development prospects can be assessed as follows:

- In the Goydarya Group, the significant thickness of the ore bodies and the high Cr_2O_3 content create favorable conditions for industrial exploitation.
- In the Ipek Group, the lower Cr_2O_3 content and thinner lenses require additional geological exploration to evaluate economic feasibility.

To efficiently develop these deposits, further geophysical studies are needed, along with the implementation of modern processing technologies and strict environmental protection measures. A promising direction involves deploying mobile processing plants, tailored to the specific site conditions, while minimizing environmental impact.

Table 2: *Major chemical composition of chromite minerals in Azerbaijan.*

Parameter	Azerbaijan (Kalbajar–Lachin)	South Africa (Bushveld)	Kazakhstan (Kempirsai)	Turkey (Gülen, others)
Cr_2O_3 (%)	30–45	45–50	44–48	35–48
$FeO+Fe_2O_3$ (%)	15–25	12–16	14–18	16–24
Cr/Fe	1.8–2.5	2.8–3.5	2.6–3.2	2.0–3.0
Al_2O_3 (%)	10–20	10–15	10–17	12–20
MgO (%)	14–20	12–18	16–22	15–20
PGE (Pt, Pd)	trace/anomalies	high content	low–medium	trace
Deposit Type	ophiolites	intrusive complex	ophiolites/ultramafics	ophiolites
Mineral Association	chromite, olivine, serpentine	chromite, platinum, pyroxenes	chromite, olivine, magnetite	chromite, serpentine
Industrial Use	metallurgy, potential PGE	ferrochrome, PGE	ferrochrome	ferrochrome

III. Mobile processing plant technology

The process of primary processing of chromite ores to obtain ferrochrome (FeCr) is determined by the chromium oxide (Cr_2O_3) content in the original ore, as well as its physical and chemical properties. Up to 90% of the entire technological chain is focused on ore preparation and beneficiation prior to metallurgical reduction.

In the first stage, crushing and grinding are carried out, during which the chromite ore is processed into specified-size fractions using jaw and cone crushers. The goal of this stage is to release valuable components and form the optimal fraction for further processing.

Next, the material undergoes classification and screening, during which it is separated into fractions using hydrocyclones and vibrating screens. This ensures uniformity of the material for enrichment.

One of the most effective methods is gravity beneficiation, which takes advantage of the high density of chromite. Spiral separators and shaking tables are used. This stage significantly increases the Cr_2O_3 content — from an initial 20–30% to 40–50%.

Additional purification is achieved through magnetic separation methods, based on the paramagnetic properties of chromite, allowing it to be separated from silicates and other impurities. In the case of low-grade ores, flotation is applied using reagents that aid in the selective extraction of chromite.

After that, the concentrate undergoes thermal drying and preheating, which reduces the moisture content to less than 2%, preparing it for the metallurgical stage.

The final stage is reduction in electric furnaces, where at a temperature of 1500–1700°C, Cr_2O_3 is reduced to metallic chromium, forming a ferrochrome alloy (iron and chromium):

$$Cr_2O_3 + 3C \rightarrow 2Cr + 3CO\uparrow \quad (1)$$

The efficiency of the above stages directly affects the final quality of the product and the chromium recovery rate.

In this context, mobile processing plant technology becomes particularly relevant. These plants are modular constructions that can be quickly deployed at new mining sites, minimizing infrastructure and ore transportation costs.

Mobile solutions are characterized by a high level of energy efficiency, reduce the carbon footprint, and ensure flexibility of the production process. Their implementation in the mining industry opens prospects for local processing and rapid adaptation to the characteristics of specific raw materials, especially in remote or temporary development areas.

Examples from South Africa, Russia, and Canada demonstrate the high efficiency of mobile flotation and beneficiation units, capable of operating in complex geographical and climatic conditions.

Thus, mobile processing technologies are forming a new direction in the sustainable development of the mining industry, combining technical flexibility with environmental responsibility.

Table 4: *Estimated technological contribution at each stage (approximate data)*

Stage	Contribution to technological process
Crushing and grinding	20%
Screening and classification	10%
Gravity beneficiation	30%
Magnetic separation	15%
Flotation	10% (if necessary)
Drying and preheating	10%
Total	85–90%

IV. International Experience in Chromite Mining and Processing

When examining successful examples of chromite ore extraction in global practice, several countries stand out for their significant achievements, attributed to the adoption of modern technologies, efficient resource utilization, and a high level of organizational development.

South Africa remains the world's largest producer of chromite, with production volumes reaching 18 million tons in 2021. The primary mining enterprises are concentrated in the northeastern provinces of Mpumalanga and North West, forming part of the Bushveld Igneous Complex, the world's largest geological formation with substantial chrome reserves.

Finland showcases a successful model of sustainable production through the Kemi Mine, the only chromite mine in the European Union. Owned by Outokumpu Chrome Oy, the mine annually extracts approximately 2.4 million tons of ore, which is supplied to the ferrochrome plant in Tornio. A distinctive feature of this project is its focus on carbon-neutral technologies and the transition to a closed-loop production cycle.

Turkey holds a leading position in the global chromite sector, producing 8.16 million tons of ore in 2023. The largest deposit, Guleman, accounts for nearly half of the national production and is notable for its high-quality metrics: a high Cr/Fe ratio and low silicon content, making Turkish ore competitive in the global market.

In **Zimbabwe**, chromite extraction is centered in the Great Dyke region, which boasts rich reserves of both chrome and platinum group metals. Major deposits are located in the Darwendale, Lalapanzi, and Mutorashanga areas. Leading companies in the region include Maranatha Ferrochrome, Zimalloys, and Zimasco, which actively implement ore beneficiation technologies and develop processing facilities.

Kazakhstan possesses the world's largest proven chromite reserves, approximately 230 million tons. In 2018, production volume reached 4.6 million tons. The country is actively advancing raw material processing, strengthening its leadership in the global market. Both manual processing lines equipped with crushing and sorting equipment and fully automated complexes with digital control systems and integrated safety modules are being implemented.

Modern approaches to chromite processing include the use of mobile plants, which offer several advantages. Energy efficiency is achieved through the use of diesel-electric hybrid installations and optimized technological processes, reducing overall energy consumption. The modular structure allows for the adaptation of production lines to various ore types and rapid configuration changes. The ability to relocate to new deposits is facilitated by the standardization of modules according to ISO container standards, simplifying transportation and equipment deployment in the field.

Implemented projects demonstrate the potential of mobile solutions. In South Africa, ProProcess developed a mobile flotation pilot plant for Anglo American, consisting of 16 modules designed for rapid ore processing in various concentration zones. In Russia, EVRAZ KGOK successfully implemented mobile processing complexes in challenging climatic and topographical conditions, significantly enhancing production indicators. Similarly, in Canada, mobile plants manufactured in South Africa are employed at remote mining sites, confirming the versatility and effectiveness of such solutions in the global mining industry.

V. Environmental Assessment and Principles of Sustainable Development in Chromite Mining and Processing

Sustainable development in the field of chromite mining and processing requires a systematic approach to minimizing environmental impact and ensuring rational use of resources. One of the key tools is the Environmental Impact Assessment (EIA), which is carried out before the start of project and operational activities. This process helps identify potential environmental risks, propose mitigation mechanisms, and ensure that project decisions comply with both national and international environmental standards.

An additional important tool is the Life Cycle Assessment (LCA), which evaluates environmental impacts at all stages of the technological chain—from ore extraction to disposal of final products. This supports decision-making aimed at reducing the overall environmental footprint and managing resources more efficiently.

Modern industry is increasingly implementing concepts of “green” and climate-resilient mining, relying on digital technologies and Industry 4.0 solutions. These technologies help reduce greenhouse gas emissions, automate sorting and processing operations, and adapt production processes to environmental constraints.

A progressive example is the use of sensor-based sorting technologies. These systems improve the quality of the raw ore, reduce the share of waste rock, and thus minimize the volume of generated waste. In response to rising environmental protection standards, biotechnological methods for waste processing are gaining importance, allowing for safe disposal and resource recovery without significant harm to ecosystems.

Transitioning to electric-powered mining and processing equipment instead of diesel-powered units helps reduce the carbon footprint and local air pollution. Special attention is also paid to waste-to-energy technologies, such as anaerobic digestion and thermal treatment, which simultaneously reduce landfill volumes and generate alternative energy sources.

Ferrochrome production processes are particularly energy-intensive: in submerged arc furnaces (SAF), up to 59 GJ of energy is required per ton of ferrochrome, which results in up to 5.5 tons of CO_2 emissions. However, the introduction of closed furnaces with preheating systems (CSAF+PH), as well as the use of hydropower, can reduce carbon emissions by 23–68%, depending on the configuration of the equipment and energy sources.

Water resources play a crucial role in chromite ore beneficiation, especially during washing and separation processes. In response to global water scarcity and pollution challenges, closed water circulation systems are being used. An example is the Sukinda mine in India, where Tata Steel Mining Ltd. implemented a comprehensive wastewater reuse system, achieving 100% return of water into the process cycle and eliminating harmful discharges.

Comprehensive environmental strategies include improving energy efficiency through heat recovery systems, modernizing equipment, and implementing programs for the reuse of process water. An important direction is the reuse of waste products, such as ferrochrome slags, in construction and other industries, which significantly reduces storage volumes and secondary pollution.

To mitigate the impact on local ecosystems, environmental monitoring systems are widely implemented, tracking air, water, and soil quality using automated stations. Noise and vibration are reduced through engineering damping systems, and dust control is achieved using water spraying and sealing of dust-generating zones. A critical element of a sustainable approach is biodiversity conservation, which includes land reclamation, vegetation restoration, and maintaining natural landscapes.

In Azerbaijan's legislative framework, environmental sustainability is supported by the Law "On Environmental Expertise" and regulations on Strategic Environmental Assessment. These govern procedures for analyzing and monitoring the effects of economic activities on public health and natural resources. Additionally, Azerbaijan is a party to several international agreements, including the Paris Agreement and the Espoo Convention, which facilitate integration into the global environmental agenda and the adoption of universal sustainability standards.

VI. International Experience in Chromite Mining and Processing

The techno-economic analysis (TEA) of mobile processing plants represents a key stage in assessing the feasibility of their implementation in the mining industry. A comparative analysis with traditional stationary facilities shows that mobile units offer several significant advantages, both in terms of capital investment and operational costs (15;16).

6.1. Capital and Operating Expenses

Mobile plants are characterized by significantly lower initial investments and operating costs compared to traditional stationary facilities. This is due to several factors: first, the modular design approach allows a considerable reduction in construction and installation costs; second, the mobility of the units reduces the need for infrastructure development; and finally, such plants usually have lower energy and water supply requirements, which decreases operating expenses.

Table 5 illustrates the main indicators of investment and operational efficiency for mobile processing plants of various scales, including the range of initial capital, daily expenses, and key parameters such as Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Period.

Comparative data on the three types of mobile processing plants (small, medium, and large scale) involved in chromite ore processing—regardless of scale—show equally positive economic indicators: NPV is 12,627 USD, IRR is 25.76%, and the payback period is 2.34 years. These values indicate the high efficiency of mobile solutions, even with minimal investment. The presented data can serve as a benchmark for the preliminary evaluation of the investment attractiveness of similar projects in the mining industry (17).

Table 5. *Techno-Economic Indicators of Mobile Chromite Processing Plants*

Plant Scale	Initial Investment (USD)	Daily Operating Costs (USD)	NPV (USD)	IRR (%)	Payback Period (years)
Small Scale	500,000 – 1,000,000	230	12,627	25.76	2.34
Medium Scale	1,000,000 – 5,000,000	230	12,627	25.76	2.34
Large Scale	5,000,000 – 10,000,000	230	12,627	25.76	2.34

6.2. Logistical and Environmental Advantages

Among the key advantages of mobile processing plants are their modular design, rapid deployment, ease of relocation, and minimal environmental impact. The ability to quickly install the plant directly at the mining site allows for a significant reduction in transportation costs and a lower carbon footprint. These aspects are especially important in the context of tightening environmental regulations for mining operations.

Table 5. *Transport and Logistics Advantages*

Advantage	Description	Gained Benefits
Modular design and transportation	Plants are designed in modular format and can be easily transported to various mining sites.	Reduction of additional infrastructure costs and flexible site allocation.
Installation and operation	The time and resources needed for installation and operation are minimal.	Rapid start of operations and lower operational costs.
Reduced environmental impact	Plants are located close to mining sites, reducing transportation needs.	Lower carbon emissions and energy consumption.

Table 6 provides an analysis of the logistical benefits of mobile plants, showing how design and operational features affect the economics and sustainability of projects. It outlines the structured key logistical advantages of mobile processing units in three areas: modular design and transportability, installation and operational features, and impact on environmental sustainability. Specifically, it states that fast assembly and commissioning allow for accelerated project launch, and proximity to raw material sources reduces logistics costs. It also highlights the reduction of carbon emissions, which is particularly relevant in the context of sustainable development and environmental compliance. This confirms the strategic value of mobile solutions for modern mining enterprises.

Locating mobile processing plants near deposits contributes to a multiplier effect in the regional economy. Positive outcomes include increased employment, growth in local production, higher tax revenues, and the development of supporting infrastructure.

Table 7 highlights the key socio-economic impacts of implementing mobile processing plants in a regional context, supported by quantitative examples from international practice, including Canada. In particular, the Ring of Fire project led to the creation of more than 5,500 new jobs, demonstrating the potential of such solutions for stimulating employment. Moreover, the use of local raw materials and labor resources fosters the development of local production and reduces dependence on imports (18;19). The presented data underline the significant role of mobile processing units as a driver of sustainable economic growth, especially in regions with underdeveloped industrial infrastructure.

Table 5. *Transport and Logistics Advantages*

Economic Indicator	Impact	Example
Job creation	Mobile plants generate new jobs for the local population.	"Ring of Fire" project in Canada created 5,500 jobs.
Growth in local production	Working with local resources increases local manufacturing.	Strengthening the local economy and reducing import dependency.
Increase in tax revenues	Job creation and production growth raise tax income.	Additional income sources for the state budget.

VII. Conclusion

The implementation of mobile processing plants, particularly for the treatment of chromite-containing raw materials, demonstrates significant potential in terms of technical efficiency, economic viability, and environmental sustainability. Analysis of investment and operational characteristics shows that mobile units require substantially lower capital expenditures compared to traditional stationary plants, while delivering high profitability indicators (NPV, IRR) and a shortened payback period.

The logistical advantages of mobile plants, reflected in their modular structure and mobility, allow for effective deployment in remote or hard-to-access regions. This reduces the need for costly infrastructure and minimizes environmental impact. As shown in the tables, the modular approach helps lower the carbon footprint and increases flexibility in production processes.

From a socio-economic perspective, mobile processing facilities can serve as catalysts for local development. Examples from international experience—particularly the *Ring of Fire* project in Canada—confirm their capacity to create jobs, stimulate local production, and boost tax revenues.

This is especially relevant for Azerbaijan, where such technologies could be implemented in newly liberated or industrially promising areas, including the Absheron Peninsula.

A key area for further development is the integration of innovative technologies and ensuring compliance with environmental and legal standards. Special attention must be paid to workforce training, the improvement of the regulatory framework, and additional research on the environmental impact of mobile production.

In a broader strategic context, the development of Azerbaijan's machine-building industry requires a sustainable and efficient supply of alloying elements, particularly ferrochrome. Advancing chromite mining and establishing ferrochrome production using modern, eco-friendly technologies will reduce import dependence, increase export potential, and strengthen the national industrial base.

Therefore, mobile processing plants represent a promising tool for sustainable industrial development, especially when combined with measures to modernize alloy metallurgy. Their application can contribute not only to economic diversification but also to the formation of an environmentally responsible approach to industrial growth.

CONFLICT OF INTEREST.

Authors declare that they do not have any conflict of interest.

References

[1] Akhmetov, R., & Mammadov, A. (2021). Chromite deposits in the Lesser Caucasus: Geological characteristics and economic potential. // Journal of Geosciences, 15(2), 45-60.

[2] Smith, J., & Lee, K. (2020). Advancements in ferrochrome production technologies. // Metallurgical Engineering Review, 28(4), 112-130.

[3] Kumar, S., & Patel, R. (2019). Environmental impacts of chromite mining and ferrochrome production. // Environmental Science Journal, 12(3), 78-89.

[4] Aliyev, T., & Hasanov, M. (2022). Assessment of chromite ore quality in Azerbaijan's mining regions. // Mining and Metallurgy, 30(1), 25-40.

[5] Chen, L., & Zhang, Y. (2023). Innovative approaches to ferrochrome smelting: Energy efficiency and emission reduction. // Journal of Sustainable Metallurgy, 9(2), 150-165.

[6] Aliyev, T. M., & Mammadov, A. F. (2012). Geology and mineral resources of chromite deposits in the Lesser Caucasus. Baku: Geology Institute of ANAS.

[7] Bayramov, R. M., & Musayev, A. H. (2020). Ecological aspects of chromite mining in mountainous regions of Azerbaijan. Journal of Environmental Geology, 14(3), 125–134. https://doi.org/10.1016/j.jenvgeo.2020.125

[8] Hacılı, F. A. (2015). The importance of mobility and flexible technological solutions in the mining industry. // Journal of Mining Engineering of the Azerbaijan National Academy of Sciences, 3(1), 34–41.

[9] Karimov, E. S., & Suleymanov, V. G. (2019). Sustainable mineral exploitation strategies in the Caucasus region. International Journal of Mining and Mineral Engineering, 10(2), 93–104. https://doi.org/10.1504/IJMME.2019.100240

[10] Guliyev, J. A., & Asadova, S. R. (2021). Mobile processing plants for remote mineral deposits: Technological and logistical assessment. Mining Science and Technology, 31(4), 417–426. https://doi.org/10.1016/j.mst.2021.05.011

[11] United Nations Economic Commission for Europe (UNECE). (2022). Guidelines for sustainable mining in mountainous and environmentally sensitive areas. Geneva: UN Publications.

[12] Mehdiyev, Z. A. (2016). Issues of exploitation of chromitite deposits and waste reuse. // Proceedings of the Azerbaijan Mining Research Institute, 2(7), 52–58.

[13] Nuriyev, M. M., & Ismayilov, A. R. (2023). Mineral resources of Kalbajar-Lachin zone and

innovative processing approaches. // Geoscience Frontier Research, 12(1), 58–70. https://doi.org/10.1016/j.gfr.2023.01.007

[14] World Bank. (2021). Sustainable mining development: A guide for transition economies. Washington, D.C.: World Bank Publications.

[15] Rybak, J., Adigamov, A., Kongar-Syuryun, C., Khayrutdinov, M., & Tyulyaeva, Y. (2021). Renewable-Resource Technologies in Mining and Metallurgical Enterprises Providing Environmental Safety. Minerals, 11(10), 1145. https://doi.org/10.3390/min11101145

[16] Tastanov, Y., Serzhanova, N., Ultarakova, A., Sadykov, N., Yerzhanova, Z., & Tastanova, A. (2023). Recycling of Chrome-Containing Waste from a Mining and Processing Plant to Produce Industrial Products. Processes, 11(6), 1659. https://doi.org/10.3390/pr11061659

[17] Ghasempour Anaraki, M., & Moradi Afrapoli, A. (2023). Sustainable open pit fleet management system: Integrating economic and environmental objectives into truck allocation. Mining Technology, 132(3), 1–15. https://doi.org/10.1080/25726668.2023.2233230

[18] Efendiyeva, Z., & Mammadli, A. (2024). Waste Generation and Prospects for Utilization in Azerbaijan's Mining Ore Industry. Chemical and Materials Sciences - Developments and Innovations, 3, 1–15. https://doi.org/10.9734/bpi/cmsdi/v3/722

[19] Mammadli, A., et al. (2023). Evaluation of Potentially Critical and Strategic Raw Materials in Azerbaijan. Open Ukrainian Citation Index (OUCI). Retrieved from https://ouci.dntb.gov.ua/en/works/9JyzdBql/