Aleksandar M. Jovović[1]
University of Belgrade,
Faculty of Mechanical Engineering
Belgrade (Serbia)

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Jadar Project in light of critical raw materials supply

Abstract: The paper provides an analysis of the global growth in demand for critical raw materials in terms of increasing demands for faster and greater use of renewable energy sources. The paper presents the most important European regulations, initiatives and projects. It also describes the basic characteristics of the Jadar Project, technical solutions, potential impacts and measures to reduce these impacts. Special attention is paid to emissions into air and water, as well as the method of disposal of industrial waste. All technical solutions are designed in accordance with the best available techniques, described in EU reference documents.

Keywords: critical raw materials, lithium, Jadar

Introduction

Accelerating climate change has set the world on a path towards carbon neutrality. Europe is pushing for drastic changes in the energy sector due to the gradual depletion of fossil fuels, accelerated development and introduction of renewable energy sources (RES) and hydrogen. Also, a higher level of energy efficiency is necessary, the fate of nuclear energy is uncertain, and there is mass electrification of the end-use sector, primarily in the field of electric vehicles (EVs), which should account for 80% of all road vehicles by 2050 (IRENA, 2022).

Energy transition includes three pillars:

- energy efficiency;
- production of renewable energy; and
- mass electrification of end-use sector.

According to the International Renewable Energy Agency, renewables are projected to account for 90% of the energy mix by 2050, requiring an increase in capacity from 2,800 GW in 2020 to 27,700 GW in 2050. The number of EVs is projected to increase from 3.4 million in 2020 to 150 million in 2050.

This scenario, based on an increase in average temperature compared to the pre-industrial era of

[1] ajovovic@mas.bg.ac.rs; https://orcid.org/0000-0003-2294-5729

1.5°C, requires that 80% of all road vehicles must be electric by 2050.

Such changes would result in a tripling of electricity demand over the next three decades, leading to a multitude of challenges. While the energy transition is essential to achieving global climate goals in a resilient and equitable manner, there are growing concerns about the availability and affordability of the minerals and metals needed to implement it (IRENA, 2021, IRENA, 2022).

Key technologies such as solar panels, wind turbines and batteries require critical materials such as lithium and rare earth elements (REE). There are therefore growing concerns about future access to these materials, the difficulty of increasing supply quickly enough to match demand, price increases and volatility, and geopolitical issues. These challenges need to be analysed and taken into account in national energy transition plans. Recently, the prices of the most critical materials have increased, in most cases as a result of increased demand and limited supply. Critical materials have unique properties and are used for different purposes. The European Union and the United States recognise 30 and 35 critical raw materials respectively, but nickel, copper, lithium and rare earth metals (neodymium and dysprosium) are attracting particular attention due to their importance and supply challenges.

The unique properties of these materials have come to the forefront of the energy transition thanks to numerous technologies, including wind turbines, solar panels, and batteries for electric vehicles and energy storage. Securing sufficient quantities of these materials is challenging for several reasons:

- It is difficult to extract them;
- Relatively few countries have deposits/reserves;
- There are no direct alternatives for them;
- Quality of natural resources is degrading;
- Only small quantities of these materials can be recycled;
- Quick increase in supply is often complicated due to fluctuation of prices resulting from an imbalance of supply and demand.

The European Commission launched its Critical Raw Materials Action Plan in 2020 (EC, 2020), having made the first list in 2011 (EC, 2023). Other EU's actions include identifying mining and processing projects in the EU that could be operational by 2025, including Horizon Europe, which should support research and innovation in critical raw materials and the development of international partnerships to secure the supply of critical materials not discovered in the EU.

The European Commission launched the European Battery Alliance in 2017 (EC, 2017). Its industrial development project, EBA 250 (EBA, 250), brings together more than 700 stakeholders from the sector with the aim of creating a strong pan-European battery industry. The European Commission's Raw Materials Information System is a knowledge and information hub on critical materials for the European Commission's policies and services.

The most important document adopted in recent years is the EU Critical Raw Materials Act (CRMA) (EC, 2024), which aims to create the conditions that would enable Europe to reach its climate goals by 2030.

The ability to quickly ramp up stockpiles and processing is key to avoiding production bottlenecks. While resources of some critical materials, such as lithium, are relatively large, current projections indicate that a massive ramp-up in production and processing will be needed in a short period of time to meet the growing demand for batteries.

Key technologies such as solar panels, wind turbines and batteries require critical materials such as lithium and rare earth elements (REE).

The influence of state institutions on accelerating the transition is particularly significant through the creation of more efficient regulatory and licensing procedures, which would enable the mining industry to respond more effectively to unexpected and sudden increases in demand. Financial support is also important, with the U.S. government investing over $350 billion, and the EU, through the Green Deal, allocating more than €250 billion. Recycling critical materials is generally feasible from a technical standpoint and is already widely applied for certain materials, particularly copper and nickel. However, in the foreseeable future, it is expected that these “new” materials will continue to dominate supply, while recycling could play a more significant role in the long term, especially in reducing the impact of mining.

LG lithium ion home battery and Solar Edge inverter solar panel system for domestic power storage installed in home garage. Adelaide, South Australia
Photo: Shutterstock

Nonetheless, it is certain that the energy transition will lead to the opening of new mines and processing facilities for specific materials. It is crucial that all activities across the sector and the entire supply chain are dedicated to sustainable exploitation, safe working conditions, local economic development, respect for cultural and natural heritage, and achieving net-zero carbon emissions. The fact that EU member states are particularly focused on this is evidenced by the updated Industrial Emissions Directive (Industrial and Livestock Rearing Emissions Directive, IED 2.0, 2024/1785). Additionally, it has been recognised that the existing Extractive Waste Directive (European Extractive Waste Directive, 2006/21/EC) is not aligned with the exploitation of new materials, prompting its revision, as well as the revision of the reference document on best available techniques in the extractive industry (Transport & Environment, 2024).

Original equipment manufacturers (OEMs), as end users, are setting increasingly higher standards for sustainable exploitation and environmental protection. These issues will no longer solely depend on the goodwill of mining and processing companies or on state regulations and controls but will also involve numerous organisations, such as the Initiative for Responsible Mining Assurance (IRMA, 2020). Geopolitical implications must be further analysed for each country individually, with the recommendation that every state, within its capabilities, prioritises national production to reduce dependence on imports. The mobilisation and allocation of financial resources to support the research and development of critical raw materials and their associated technologies promise countless benefits and could become a driving force for the energy transition. Market-based approaches to expanding supply, as well as political interventions to address geopolitical realities, are equally necessary. Investments in exploration, mining, and processing will increase market resilience and diversify supply. Governments should also aim to reduce reliance on critical materials.

Projected demand for critical raw materials

The prices of critical raw materials fluctuate significantly on global markets due to wars, stockpiling, disruptions in the global electric vehicle market, and similar factors. Lithium prices have been particularly volatile in recent years. As buyers stockpile lithium carbonate and create reserves, prices were initially very high but were followed by an inevitable drop (SPGLOBAL, 2024). Prices peaked at 27 USD/kg at the end of 2017 before dropping to 6 USD/kg by mid-2020, then rising again to 14 USD/kg by mid-2021. Since early 2021, they have consistently increased, reaching approximately 52 USD/kg in January 2022, with a record high of 85 USD/kg on 14 November 2022. Subsequently, they dropped to 69 USD/kg (69,000 USD/tonne) and are now around 10.6 USD/kg, with the price of lithium carbonate approximately 18,000 USD/tonne.

The price of copper is projected to reach 15 USD/kg in the coming years (currently 9 USD/kg), followed by further increases (Dizard, 2022), given that electric vehicles and renewable energy are expected to account for 72% of the total growth in demand for refined copper by 2025.

The lithium and electric vehicle markets are closely linked. Approximately 17 million electric vehicles are currently in use globally, with sales this year reaching 1.1 million vehicles and showing a growth trend, albeit slightly less than anticipated a few years ago. Demand for lithium for EV batteries is expected to grow, with 75% of lithium demand by 2030 projected to come from battery production (IRMA, 2022).

Nickel prices rose to their highest level since 2012, reaching 25 USD/kg in February 2022 (Reuters, 2022), while the current price is 16 USD/kg (Trading Economics, 2024). Prices are expected to continue rising in the coming years.

The prices of neodymium have risen since mid-2020, now reaching a level of 516 USD/kg (Trading Economics, 2024). Unlike gold and silver prices, tracking REE prices in real time is challenging because they are not traded on global public exchanges. REE prices have increased due to higher production costs in China, which hosts the majority of processing capacities, and rising demand. If prices continue to rise, manufacturers will be incentivised to seek alternative materials.

The following image presents projections of consumption for certain critical raw materials, modelled by IRENA under a scenario where the average temperature does not exceed 1.5°C above pre-industrial levels by 2100.

Lithium is used for making EV batteries. Image shows a Fiat Grande Panda, production of which recently launched in Serbia.
Photo: Dimitrije Gol

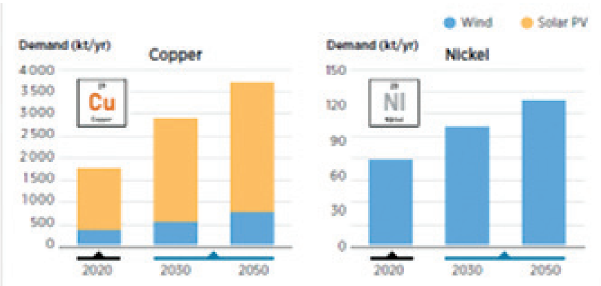

Figure 1: Projected demand for copper and nickel under the IRENA 1.5°C scenario (IRENA, 2022)

Strengthening research and international cooperation across various fields can help reduce supply risks. For example, efforts are underway to lower the REE content in permanent magnets. The silver content in solar PV systems has significant potential for material efficiency improvements. Suppliers typically seek such solutions to reduce production costs. Research funded by public and private funds plays a key role in accelerating this process.

Other areas of research include the development of new mining technologies, expansion of domestic sources of critical materials, improvement of material and processing efficiency, acceleration of product innovation and identification of alternative materials, development of recycling technologies, and enhancement of the sustainability of mining and processing operations. The most desirable option is the reuse of products that have reached the end of their technical life whenever possible. For example, lithium-ion batteries whose capacity has dropped to 70–80% of their original capacity can still be used for stationary energy storage applications in the electrical grid. If a sustainable option for product reuse does not exist, it can be remanufactured using primary, secondary, and refurbished materials (Gaustad et al., 2018). The third option is recycling.

Close collaboration and data sharing could avoid duplication of research efforts and accelerate outcomes. Focusing on these areas of research and development could increase productivity and cost-effectiveness across the entire value chain while improving the supply of critical materials.

After the adoption of the European Critical Raw Materials Act, through which the EU seeks to become more self-reliant in the extraction and processing of critical raw materials, further expansion of projects is expected, with this development increasingly being referred to as the European mining renaissance. In the largest European deposit, located in the Upper Rhine Valley, lithium is found in geothermal brine reservoirs, where the extraction process has a smaller environmental impact. There, the Australian company Vulcan plans to start commercial production of battery-grade lithium by the end of 2026. However, it appears that the first European lithium mine will be opened by late 2026 in the alpine region of Carinthia, 270 km from Vienna and 20 km from the industrial town of Wolfsberg. This will be an underground mine similar to Jadar, where lithium is also found in hard rock, although the estimated potential of the deposit is significantly smaller. One of the richest European hard-rock lithium deposits is located on the German-Czech border, in the mineral zinnwaldite. The Czech Republic is developing the Cínovec project, while Germany is working on the Zinnwald project. Portugal also holds significant lithium reserves, with the regional government of Extremadura declaring the San José project as one of regional and general interest. The Barroso project, led by the British company Savannah Resources, is the most important European spodumene-based lithium deposit, another mineral found in hard rock. Lithium mining projects are also underway in Spain, Finland, Ireland, and the United Kingdom, with two of these projects located in Natura 2000 protected areas. A major lithium project, Emili, by Imerys, is being developed in central France, near protected beech forests that are home to numerous animal and plant species (Reutner, 2024).

The Jadar Project – Technical Characteristics and Environmental Impacts

Basic framework

Serbia has the potential to become part of Europe's industrial revolution, but many developments surrounding the Jadar Project threaten to leave it on the side-lines of success. Serbia's potential in battery and electric vehicle production is significant due to:

- Its own unique deposit of high-quality lithium;
- A rich tradition in mining and industrial processing;
- Highly qualified experts and researchers;
- Industrial zones that can support the development of related industries;
- Proximity to major OEMs.

The Jadar Project aims to exploit and process jadarite in one of the largest lithium deposits in the world. It is located near Loznica, in the Podrinje and Posavina regions, east of the Drina River and south of the Sava River, where, during fieldwork in the Jadar valley in 2004, a new mineral – jadarite – was discovered. The newly discovered mineral is the starting raw material for obtaining lithium, specifically lithium carbonate, which is essential for battery production and electronic components, as well as boron, which has extensive applications in the chemical industry. During the exploration of the deposit, Rio Tinto investigated and defined the technology for ore exploitation, the technology for concentrating the ore into jadarite concentrate, and the process of dissolution and selective crystallization to produce the final market products. The National Strategy for the Sustainable Use of Natural Resources and Goods (Official Gazette of the RS, No. 33/12) stipulates that the geological survey project for lithium and boron (Jadar Basin) be completed by the end of 2014. Decrees (Official Gazette of the RS, Nos. 104/16 and 106/16) provide for activities related to the opening of boron and lithium mineral deposits in the Jadar River valley. The Draft Spatial Plan of the Republic of Serbia (section 4.1) defines the commencement of the exploitation of lithium ores (near Loznica) and molybdenum as one of the priority planning solutions by 2025 (MGSI, 2021). Before beginning the administrative procedure related to the development and obtaining approval for the environmental impact assessment study, in accordance with the Spatial Plan for the Special Purpose Area for the implementation of the Jadar Project for the exploitation and processing of jadarite (Official Gazette of the RS, No. 26/20), the Location Conditions were issued. These conditions were issued for the phased construction of the processing plant with the aim of preparing the conceptual design, the construction permit project, and the implementation project.

Alongside the development of the spatial plan, a report on the strategic environmental impact assessment of the spatial plan was prepared (Official Gazette of the Republic of Serbia, No. 36/17).

The spatial plan serves as the planning basis for the implementation of the Jadar Project for the exploitation and processing of jadarite (development of the mine, industrial facility, and necessary infrastructure), as well as for the protection, utilisation, and organisation of the special-purpose area. The spatial plan covers an area of 293.91 km^2 within the territories of the following local government units:

- ❖ City of Loznica – entire cadastral municipalities (c.m.): Runjani, Lipnica, Bradić, Brnjak, Veliko Selo, Jarebice, Draginac, Simino Brdo, Cikote, Šurice, Stupnica, Slatina, Korenita, Gornje Nedeljice, Donje Nedeljice, Grnčara, and Šor;
- ❖ Municipality of Krupanj – entire cadastral municipalities (c.m.): Kostajnik, Dvorska, Brezovice, Krasava, and Cerova.

Regarding the concept of spatial development, future functions, and land use, the area needed for the implementation of the Jadar Project is divided into several zones and subzones. To enable the operation of the planned complex, it is necessary to construct a railway line and roads to connect the complex to the existing infrastructure. Additionally, it is necessary to build a gas pipeline, a pipeline for raw water transport from the source to the facility, as well as telecommunications and electrical connections. The planned transport of auxiliary raw materials and finished products will be carried out by rail and road. The transport-infrastructure corridor zone (planned transport and infrastructure systems) for the special-purpose area includes the corridor of the planned railway line, the new section of state road IB class No. 27 Valjevo–Loznica (key for accessing the special-purpose complex), the corridor of the planned lateral high-pressure gas pipeline, and the technical water pipeline. This zone covers an area of 480.02 hectares.

Project description and ore processing production process

The jadarite mine with its processing facility is divided into three units:

- ❖ Underground section of the mine;
- ❖ Aboveground section of the mine;
- ❖ Ore processing facility.

The block diagram of the technological process is shown in Figure 2.

The conceptual designs for the processing facility were prepared by Belgrade-based Termoenergo-Inženjering in 2022 and are listed in the references of the environmental impact assessment study for the Jadar Project—phased construction of the processing facility for jadarite processing, “Jadar”, in accordance with the regulations of the Republic of Serbia (MF, 2023). Additionally, two conceptual designs for the disposal of industrial waste at the Štavice landfill site were developed by the Belgrade-based Jaroslav Černi Institute in 2020, which served as the basis for drafting the Environmental Impact Study for Industrial Waste Disposal (MF, 2023). The Environmental Impact Assessment Study for the underground exploitation of the Jadar lithium and boron deposit (RGF, 2023) was created based on the Feasibility Study for the underground exploitation of the Jadar lithium and boron deposit (RGF, 2021) and numerous other documents listed in the references of this study.

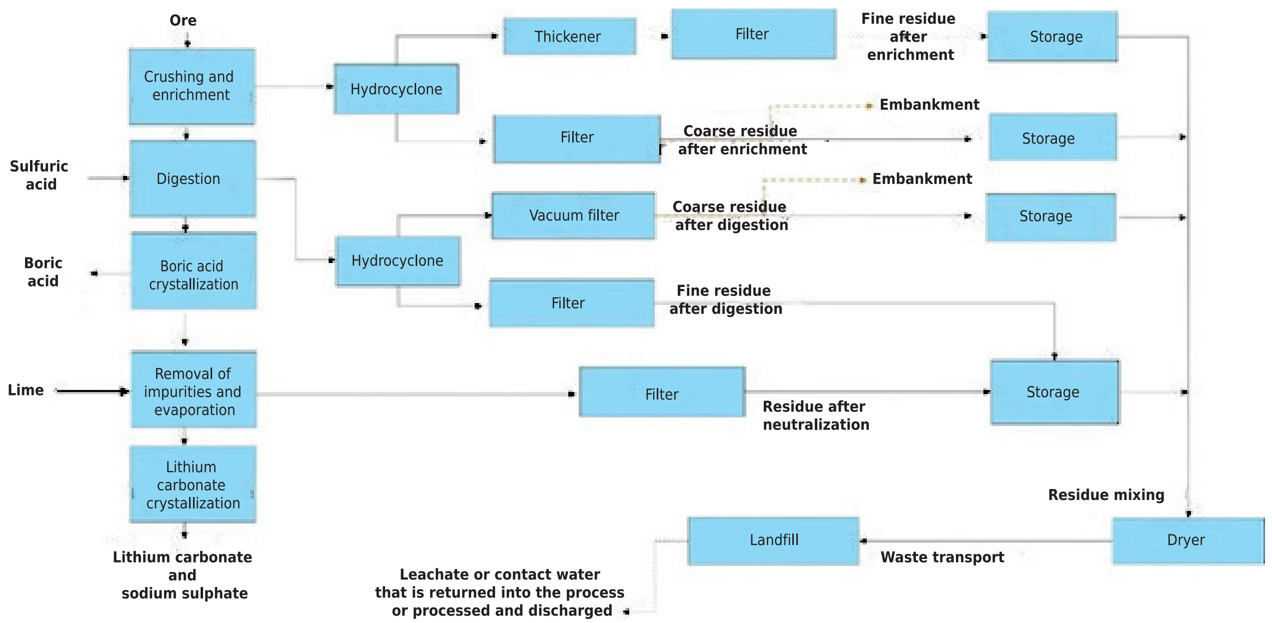

Figure 2: Simplified technological diagram of ore processing (MF, 2023b)

The project proponent, Rio Sava Exploration, hired several specialised engineering companies, including HATCH, to develop a new and innovative technology for producing targeted mineral products such as lithium carbonate, boric acid, and sodium sulphate. Sample testing and research were conducted in Bandura (Australia) to test and develop the new technology. To date, over 2,000 tests have been carried out to optimise the solution for extracting minerals from jadarite ore.

All studies were conducted in accordance with the Law on Environmental Impact Assessment (Official Gazette of the Republic of Serbia, Nos. 135/04 and 36/09) and the Regulation on the Content of Environmental Impact Assessment Studies (Official Gazette of the Republic of Serbia, No. 69/05).

The entire facility and all its systems have been designed in compliance with BAT (Best Available Techniques) as per the reference documents (BREF):

- Emissions from storage, 2006;
- Non-ferrous metal industries, 2017, BAT conclusions 6/2016;
- Energy efficiency, 2009;
- Common waste water and waste gas treatment/management systems in the chemical sector, 2017, BAT conclusions 6/2016;
- Industrial cooling systems, 2001;
- Inorganic chemicals – ammonia, acids, fertilisers, 2007;
- Waste treatment, 2018, BAT conclusions 8/2018.

A detailed review of compliance with BAT/BREF is provided in a dedicated chapter of the study. In accordance with Article 17 of the Law on Environmental Impact Assessment (Official Gazette of the Republic of Serbia, Nos. 135/04 and 36/09) and the Regulation on the Content of Environmental Impact Assessment Studies (Official Gazette of the Republic of Serbia, No. 69/05), the environmental impact assessment studies include:

1. Information about the project proponent;
2. Description of the location planned for project implementation;
3. Description of the project;
4. Overview of the main alternatives considered by the project proponent;
5. Overview of the environmental condition at the location and its surrounding area (micro and macro location);
6. Description of potential significant environmental impacts of the project;
7. Assessment of environmental impacts in case of accidents;
8. Description of measures intended to prevent, reduce, and, where possible, eliminate any significant harmful impacts on the environment;
9. Environmental monitoring programme;
10. A non-technical summary of the data listed in points 2–9;
11. Information on technical deficiencies, lack of appropriate expertise and skills, or inability to obtain necessary data.

The ore processing facility is located in the subzone for production and industrial activities (Subzone 2A) and encompasses the space and areas required for constructing and forming a complex where ore is processed and lithium carbonate, sodium sulphate, and boric acid are produced. Within the Jadar Project, the following main production units can be identified:

- ❖ Underground mining of jadarite ore of project-grade quality, approximately 1.64% Li_2O;
- ❖ Aboveground section of the mine complex, including ore beneficiation and the production of jadarite concentrate with approximately 3.04% Li_2O;
- ❖ Industrial processing of jadarite concentrate to obtain marketable final products, including boric acid, lithium carbonate, and by-product sodium sulphate (referred to as Subzone 2A for production and industrial activities in the spatial plan);
- ❖ Industrial waste landfill;
- ❖ Freshwater supply for the Jadar Project by extracting water from the Drina River alluvium, pumping groundwater from the mine pit, using water for processing, and finally treating wastewater before discharge into the Jadar River;
- ❖ Supply of electrical energy through two 110 kV overhead lines and two power transformers of 63/75 MVA (with the possibility of load up to 82 MVA in critical situations). The electrical energy requirements of the special-purpose complex (processing plant) are approximately 43 MW, with a maximum expected or peak load of around 54 MVA;
- ❖ Supply of natural gas for production and industrial activities to the metering and

regulation station within the complex (gas supplied through a pipeline under a pressure of 50 bar, over a length of 11 km);
- Connection of the complex with optical cables to ensure modern communications;
- Construction of access roads for the delivery of raw materials, transportation of workers, and dispatch of products;
- Construction of a railway connection from Loznica to the Jadar Project site, with a length of 8.6 + 4 km, for receiving consumables and dispatching products.

The most important parameters of the project:
- Raw material base: the Jadar Project aims to mine and process 1.9 million tonnes per year of jadarite ore;
- Finished products: jadarite mineral serves as the raw material for producing lithium carbonate (~56 kt/year), boric acid (~286 kt/year), and sodium sulphate (~259 kt/year) as a by-product;
- Gas connection: the planned annual gas consumption is 2,603,000 GJ. This conceptual project includes the gas distribution within Subzone 2A;
- Telecommunications network connection: this conceptual project includes internal telecommunications systems within Subzone 2A;
- Raw water connection: the conceptual project includes a connection to the raw water supply pipeline from the Drina River and distribution of raw water within the processing plant in Subzone 2A. For the operation of the facility, raw water will be sourced from the alluvial deposits of the Drina River, directly next to the river. The daily maximum water intake from 2025 to 2040 will be 4.8 million litres/day, with the expected average water intake being 1 million litres/day, depending on the amount of groundwater infiltration into the mine;
- Drinking water connection: the supply of drinking water will be from the Loznica water supply network. The average water consumption is 0.55 l/s or 48 m^3/day;
- Control of dust emissions: using bag filters;
- Control of sulphur compound emissions: a scrubber is planned for treating the waste gas from the dissolution process to remove sulphur compounds such as H_2S and acid mist from the flow of waste gas rich in carbon dioxide;
- Collection and discharge of technological wastewater: within the processing plant, there is a planned facility for treating sanitary wastewater, as well as a facility for treating technological wastewater. The wastewater will be discharged into the Jadar River after treatment. The conceptual project includes the discharge of treated wastewater to an external connection to the wastewater pipeline leading to the Jadar River.
- Disposal of solid waste: solid waste generated during processing will be disposed of at the industrial waste landfill. Trucks will transport the waste from the treatment facility to the landfill.

Consumption of basic chemicals:

- Sulphuric acid (t/year) 344,414;
- Hydrated lime (t/year) 62,085;
- Sodium carbonate (t/year) 105,000;
- Sodium hydroxide (t/year) 40;
- Hydrochloric acid (t/year) 1,874.

Overview of key impacts and treatment methods

- **Air**

Emissions will be minimized by applying the best available techniques and practices (filters, continuous air quality monitoring, and preventive measures such as water spraying nozzles, working hours, etc.).

Modelling: changes in the project design were reflected in the air quality modelling, which resulted in the development of five different models over several years. The results of the models often led to changes and improvements in the project itself.

- The air pollution models were created based on assumptions that represent the worst-case scenario. They do not reflect the actual conditions on the ground during the works, but are intended to properly select appropriate measures to avoid or mitigate potential impacts of the project on the environment.
- The modelling of the Jadar Project's impact on air quality during the construction, operation, and closure phases was carried out for the following pollutants: TSP (total suspended particles), suspended particles PM_{10}, $PM_{2.5}$, NO_2, SO_2, CO, HCl, and SO_4^{2-} as an indicator of the presence of H_2SO_4.
- The model covers sources associated with the project without background pollution. As part of the analysed scenarios, simulations of pollutant dispersion were carried out, with the pollutant concentrations obtained from the model being presented graphically through ground-level isopleths (lines connecting points with the same concentration of the pollutant). Hourly data for a full five calendar years (2016–2020) were used for meteorological conditions. The results of the air quality modelling were compared with reference values and presented in accordance with the defined presentation method and averaging periods from the Regulation on the conditions for monitoring and air quality requirements (Official Gazette of RS, Nos. 11/10, 75/10, and 63/13).
- Additionally, a conservative approach was used for modelling pollutant dispersion – unfavourable meteorological conditions, maximum activity during working hours, and maximum equipment usage;
- The AERMOD software package (US EPA) was used to assess the impact on air quality (an example of one result is shown in Figure 3).

Impacts identified through modelling:

- Dust emissions, represented as total suspended particles (TSP), were identified as the main pollutant for all project phases. TSP – areas with exceedances are mainly found along the southern boundary of the main project area, the southwest boundary of the Štavice landfill, and along the access road to the Štavice site. The concentration exponentially decreases to 500 m from the boundary, where it is within the specified limit values;
- NO_2 is emitted around steam boilers, mobile equipment, and the transport route, reaching

the limit value at a distance of 200 m. Due to the intensive use of trucks and machinery, the concentration of NO_2 could be higher than the prescribed air quality standard, but only for short periods and within the allowable short-term exceedances in accordance with regulations;

- The potential impact of other pollutants (CO, HCl, and H_2SO_4) on air quality within the model domain is low and would not make any significant difference to air quality. The impact of these pollutants is limited to the immediate surroundings of the equipment and the use of protective gear at the workplace for plant operators.

Through modelling the dispersion of potential pollutants, zones of risk were identified based on the worst-case scenario, and further measures will be adopted and implemented to reduce these impacts and maintain concentrations within permissible limits or below the threshold values. Mitigation measures:

- ✓ Protective barriers;
- ✓ Dust collection system and exhaust system for primary dust-generating equipment;
- ✓ Air emission treatment devices (venturi scrubbers);
- ✓ Maintenance and cleanliness measures on-site;

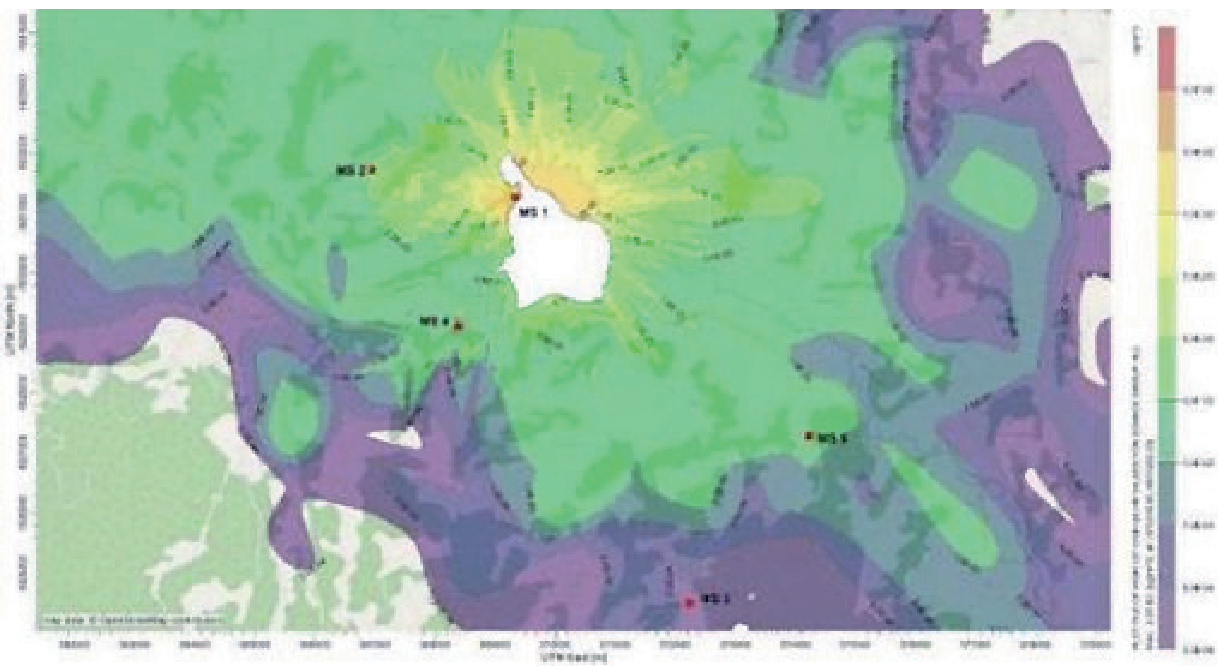

Figure 3: Maximum ground-level concentrations of H_2SO_4 for a one-day averaging period [μg/m³] (MF, 2023a).

- ✓ Disposal of waste materials from lower heights;
- ✓ Avoidance or minimisation of soil transport;
- ✓ Use of water sprinklers;
- ✓ Covering, closing, or renewing vegetation on landfills and storage areas wherever feasible;
- ✓ Monitoring wind conditions;
- ✓ Management of working hours;
- ✓ Speed limit enforcement;
- ✓ Energy efficiency measures to reduce fuel and electricity consumption.

- **Water**

Water management planning is one of the biggest challenges, with the task, on one hand, of ensuring the optimal amount of water necessary for the mining and processing of mineral raw materials, while, on the other hand, ensuring that no harmful impacts occur on the water regime in the immediate vicinity of the future complex. During the development of the Jadar Project, and in the preparation of technical documentation, a water management system was designed and planned to maximise water recycling, with around two-thirds of the water balance coming from internal sources (underground mine drainage and rainwater collection at the site), aiming to minimise the amount of water that needs to be supplied from external sources. Any excess water that may occur in the system, once the possibilities for recycling or reuse are exhausted, is treated and discharged in accordance with the environmental protection requirements and objectives.

The analysis of the water balance and water demand planning during the development of the Jadar Project was carried out using dedicated models, which have the ability to perform complex calculations with various variable input parameters to optimise the use of water resources and ensure proper planning. These complex models, with every change (e.g. in mining plans or technological processes), result in adjustments to the water balance itself, and both input and output values have undergone certain changes over time. The latest model was developed in 2023.

The operational philosophy for managing surface runoff is designed so that all three lagoons for surface runoff acceptance, as well as the process water basin, remain “empty”, ensuring that their full capacity is always available to accommodate any extreme rainfall events. As a result of this philosophy, there is a need to supply “fresh” water when there is a shortage of water on the site itself. “Fresh” water is used to supply the raw water reservoir to meet the process plant's water needs in situations where there is insufficient inflow from the underground mine drainage system or from collected rainwater. The peak demand for supplying “fresh” water (P100) is estimated at 4.2 million litres per day (approximately 48 l/s), which occurs in the 33rd year of plant operation. The average value varies over the years, ranging between 1 and 2 million litres per day (11 and 23 l/s).

In cases where there is an excess of water in the lagoons for surface runoff acceptance, as well as in the process water basin, the wastewater treatment plant in the process facility receives information that there is an excess capacity that needs to be treated and eventually discharged into the Jadar

River. The maximum wastewater flow to be discharged into this river occurs in the early days of the fifth year of plant operation (the first year of the phase reaching normal production levels), when the full capacity of the double reverse osmosis system is used to treat water for discharge into the river, and when the need for water in the process facility is reduced (during the phase of reaching normal production levels).

From the 5th to the 7th year, production increases and the water demand in the process facility rises. Operational activities reach normal values in the 8th year, with the required capacity for water discharge into the river being 90 m^3/h (25 l/s). The average wastewater flow varies around 0.5 million litres per day (approximately 6 l/s).

It is important to emphasise that the supply of raw water and the discharge of treated wastewater do not occur simultaneously; these are two separate operations conditioned by the amount of water in the water collection lagoons. In other words, when there is an increased influx of groundwater or atmospheric precipitation, it is necessary to release the excess water that occurs in the system. The opposite process occurs when there is insufficient water inflow, and additional quantities need to be supplied from the alluvium of the Drina River.

In the case of inadequate water management during all phases of the Jadar Project development, both surface runoff and wastewater from the planned complex site, there may be a disruption of the groundwater and surface water regime at the site. The main risks associated with the planned mine and processing plant (as a single entity), which have been thoroughly examined and may arise when planning such activities, are: the impact of drainage on the water regime, wastewater and its treatment and evacuation, water abstraction for the operation of the planned plant, and the occurrence of high waters and their impact on the planned facilities. The location planned for the construction of the industrial waste landfill, due to its physical separation, can be regarded as an independent entity, and the associated impacts can be considered independently. The dominant impacts related to the planned landfill concern the management of surface runoff and the control of process waters that may arise at this location.

- **Waste**

The principle of waste management from production processes is shown in Figure 4.

The development of the Jadar Project also involved certain changes in the context of waste management solutions, aimed at reducing environmental impacts and optimising the production process. The existing technical solution involves mixing all three process residues (from ore beneficiation, concentrate dissolution, and impurity removal) into a hydro-mixture, which is then filtered, dried to a moisture level of 25%, and subsequently disposed of in dry form at the Štavice landfill. Additionally, approximately 29% of the process residue can be used in mining backfill – all to reduce negative environmental impacts.

The proposed technological solution for waste management was selected based on the consideration of the most environmentally favourable option, in accordance with Articles 6 and 44 of the Waste Management Act (Official Gazette of RS, Nos. 36/09, 88/10, 14/16, 95/18 – other law, and 35/23). This will ensure that the chosen technical solution minimises the surface area and volume of space required for the formation of the landfill, reduces the harmful properties of the waste, improves the geotechnical stability of the disposal site, and facilitates the process of waterproofing and collecting leachate compared to the case where the fractions of the residue are disposed of separately. The aforementioned technical solution is subject to obtaining permits and will be further optimised with the aim of achieving a zero-waste process, meaning that all process residue will be utilised as a product with a specific purpose (mining backfill, construction material, agricultural industry, road construction, and others).

The industrial waste intended for disposal at the Štavice industrial waste landfill, according to the latest waste characterisation conducted based on laboratory analyses by the Anachem laboratory and in accordance with the requirements of the Regulation on Waste Categories, Testing, and Classification (Official Gazette of RS, Nos. 56/10, 93/19, and 39/21), is defined as waste with index number 19 03 06*. It is classified as hazardous waste due to the increased boron content in the leachate, according

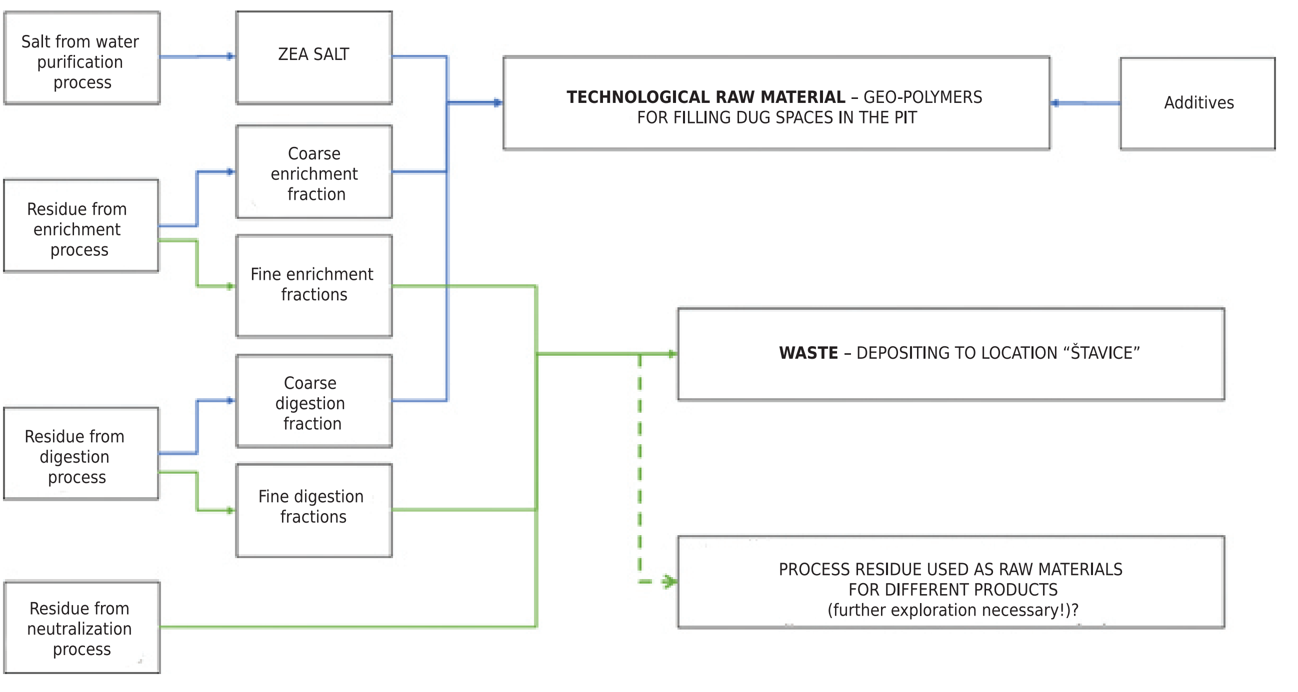

Figure 4: Principle of waste management from the processing of jadarite ore (MF, 2023b).

to the hazardous characteristics H15. The waste does not contain hydrocarbons or compounds of oxygen, nitrogen, and sulphur, nor organohalogen compounds. According to the Regulation on Waste Disposal at Landfills (Official Gazette of RS, No. 92/2010), the subject waste can be disposed of at hazardous waste landfills.

The sample on which the characterisation was conducted represents a mixture of the three mentioned waste streams in a way that reflects the proportional share of specific streams in reality, according to the scenario of using ~29% of the total mass of the waste for mining backfill.

Within the subzone of the landfill, there are the industrial waste landfill and associated facilities, organised and grouped in accordance with the technological scheme and investor requirements, namely:

- industrial waste landfill;
- initial dam of the landfill;
- reception basin for collecting water;
- facility for treatment and processing of collected water and reservoirs;
- peripheral channel for collecting surface water;
- access roads (gravel);
- covered space for parking machinery and trucks;
- well for water supply and water treatment facility;
- backup well for water for dust emission control;
- transformer station;
- other facilities of the same or compatible purpose for the disposal of industrial waste and an administrative building for employees.

Initially, the waste will be disposed of at the eastern end of the Štavice valley in layers up to 95% compaction according to the standard Proctor test. The landfill will have active and inactive sections (zones). Active zones will be those where the waste is disposed of, spread, and compacted. Waste disposal will take place on active working levels, which will raise the landfill to the planned elevation. The advantages of this construction approach include the following:

- Operational flexibility for transport and waste disposal;
- Small landfill footprint at the start of operations due to reduced capital costs;
- Progressive closure of the landfill after each phase reaches the planned height.

The impact of industrial waste disposal on the surrounding environment covers the area marked as Subzone 3B and relates to the area where impacts may occur due to the disposal of industrial waste. The boundary of Subzone 3B is determined at a distance of 500 m from the boundary of Subzone 3A. Disposal of industrial waste (dry residue) at the landfill provides more favourable parameters in terms of environmental impact and the potential for more efficient risk management within the landfill impact zone compared to an alternative solution involving a tailings pond (disposal of liquid waste).

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The layout of the mentioned facilities is shown in Figure 5.

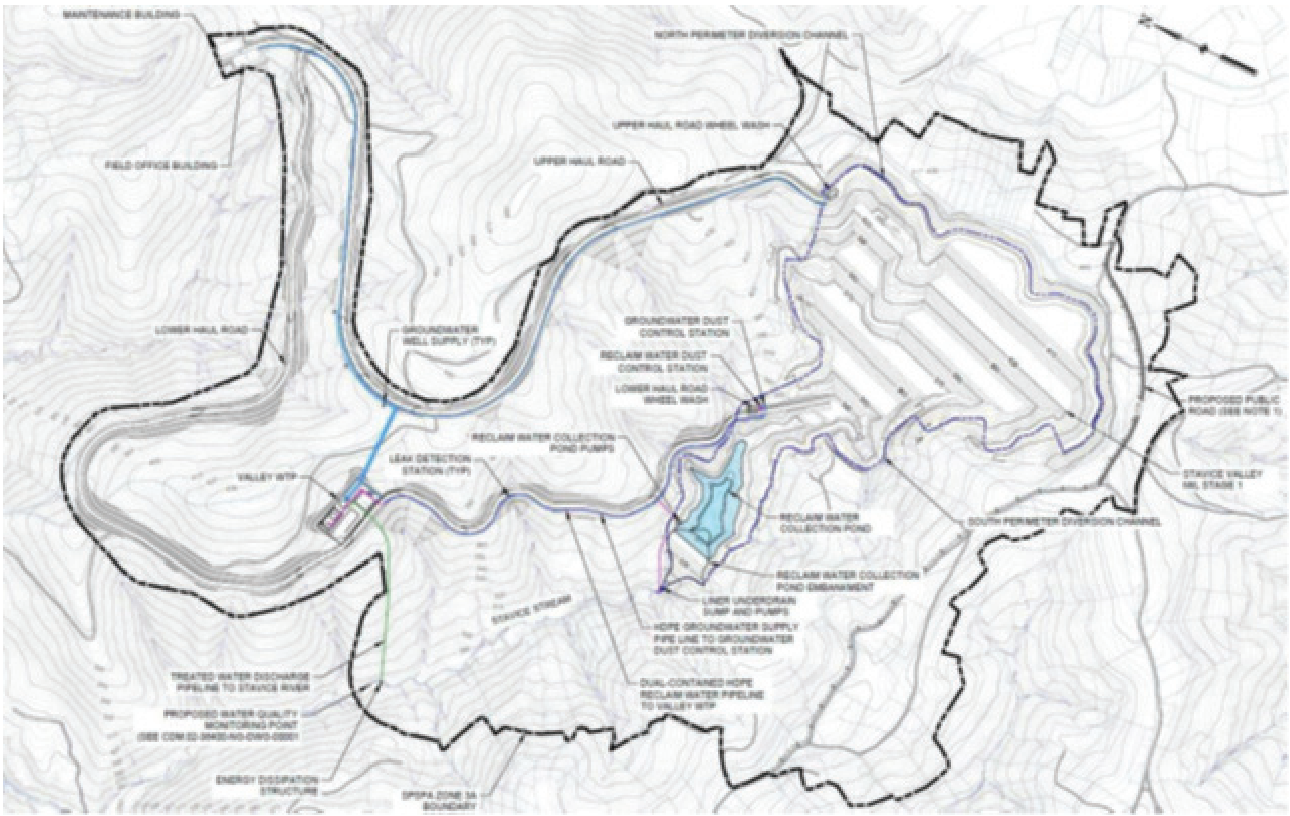

Figure 5: Layout of the industrial waste landfill (MF, 2023b)

Conclusion

The draft studies are based on research conducted by over 100 domestic and international independent experts, including 40 university professors from more than 10 faculties. Scientific research shows that the Jadar Project can be safely implemented while adhering to the highest domestic and international environmental protection standards.

The drafts of the published studies are the result of a total of six and a half years of work, which began with the collection of baseline data, followed by more than 23,000 biological, physical, and chemical analyses of soil, water, air, and noise. The draft studies are comprehensive and based on extensive data that enable precise conclusions about potential environmental impacts and the corresponding protection measures. The publication of the draft studies, comprising 2,000 pages with accompanying explanations, does not mark the beginning of the official environmental impact assessment procedure as envisaged by the law of the Republic of Serbia.

The working draft studies of the environmental impact assessment for the Jadar Project represent the most comprehensive studies of this kind ever conducted in Serbia. The studies provide a detailed analysis of the existing environmental conditions, evaluate the technical solution and its potential impact on the environment and public health through the development of numerous models, calculations, and experiments. Based on this, the studies outline all known potential risks and propose appropriate solutions to mitigate these impacts, demonstrating that this project can be responsibly and safely implemented. The involvement of NGOs, the academic community, design companies, academies, and the interested public in the forthcoming public debate will further ensure the excellence of the project.

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