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Lithium extraction and processing: the future that should not be easily dismissed

Dear readers, from the texts before you may be surprised to learn that back in the Middle Ages, King Uroš I brought German (Old Saxon) miners to these territories and that, thanks to his long-term vision, poor Serbia began digging silver and develop economically faster, catching up with its neighbours. There may have been disapproving voices even at that time, but general welfare was louder than them. Seven and a half centuries later, history repeats itself, and our state is facing similar challenges: whether to extract lithium while observing the highest ecological standards and develop the economic and political capital of entire humanity, or stay trapped in the fears from ecological differences perhaps lurking from the depths of Jadar.

The study drafts by more than a hundred Serbian and international independent experts, including 40 university professors from over 10 faculties show that "Jadar" project may be safely implemented with the application of the highest domestic and international standards. After six and a half years of thorough work and more than 23,000 biological, physical and chemical analyses of soil, air and noise, on more than 2,000 pages, a comprehensive study has been prepared with accurate data about potential impacts on the environment and with adequate protection measures. By publishing a comprehensive review of the lithium extraction risks, we place a special emphasis on environmental sustainability and new technologies to be integrated in the protection measures. Moreover, we see continued monitoring of the environment as a key and mandatory strategy of sustainable mining. Surface waters, soil and air are important resources for preserving public health, which no exploitation can ever bring into question.

Today, lithium is a *par excellence* complex political issue in Serbia, and to provide the best response, the academic debate is the best manner of informing the public in a quality way, because only a thus-adopted solution may be good for all. Hence this thematic edition, as a contribution to the debate which should take place in a broader scientific community. Global energy pre-composition with an increasing number of surprises on the political chess board, with lithium as a strategic stake, enables us to participate in the game of power redistribution with an opportunity of improving Serbia's position in economic, energy and, at the same time, in political and security terms. Our public, just as on many similar occasions, is divided. Plenty of disinformation, conspiracy theories, subversive acting of those who would like to gain extra profits even before the beginning of the project implementation, rumours, hearsay, lies, spins and fear from changes have entered the public space, spreading moral panic and suspicion about environmental pollution that will destroy the terrain and the population. Scientific arguments have quieted down and been replaced by sound and fury towards those who support lithium extraction.

In today's Serbia, everything is politics. Sport, education, agriculture, the church, economy, history, vaccination and the theatre – and, as we can see now, ore extraction. It is much more devastating that the civilian, political and professional public seem not to hear or have any mutual understanding. This issue of *Napredak* is our academic contribution to the social dialogue, whereas we are aware that the dialogue also calls for the readiness of those who do not want to hear about, let alone to understand arguments. Nevertheless, we hope that that those who want will be able to draw appropriate conclusions from the scientific papers published here.

Articles

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Critical mineral resources – lithium (Li)

Abstract: This paper analyzes the concepts and methodologies used by the USA and the EU for establishing the list of critical raw materials (CRM). Critical raw materials as key elements for national security and economy play an important role in energy, industrial and military technologies. The USA has adopted the methodology based on economic vulnerability, disruption potential, trade exposure and supply risk, while the EU uses the criteria of economic importance and supply risk. The CRM lists in the USA and the EU are regularly updated so that the USA included 50 raw materials in its 2023 list, while the EU has 34 raw materials in its list. This paper also considers the importance of lithium as one of the key raw materials at the global level and gives a review of large lithium producers and suppliers, as well as Serbia's potential in this field. Lithium is particularly important for the production of batteries, electronics and space technologies.

Keywords: critical raw materials, US and EU methodology, raw materials of Serbia, lithium, global market, economic and technological aspects

Introduction

The main burning topics worldwide have been analyzed referring to what critical raw materials are, to the manner of determining the critical status of a particular raw material and to the methodology used for determining this status. The main features have been presented of the Critical Raw Materials Act adopted by the EU. The second part deals with the problems related to lithium as one of the most important raw materials from the list of critical raw materials, as well as with the projection of its effect on Serbia's economy.

The term critical raw materials (hereinafter: CRM) was established as a political, geostrategic and military term, and not as a technical or geological one. This term was not used several years ago, but there were only descriptive reports about the

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problems related to certain raw materials and the need of Western economics to ensure the supply of these raw materials. It can be concluded from numerous published expert papers and analyses by the geological institutes of the USA, Canada and EU institutions dealing with the problems of geology, mining and trade in raw materials (metals, non-metals, natural and other materials). Lithium is one of important materials or raw materials from the CRM group and it is included in all lists (the USA, the EU, Australia, Canada, India, Norway...). Lithium is used for different purposes: n non-rechargeable batteries as an anode, in the electrolyte and cathode of lithium-ion rechargeable batteries, lithium-based greases, aluminium production, air purification, in space technology, glass industry, ceramics, foundry industry (iron and steel castings), for special types of rubber and plastic.

Critical raw materials

Currently, there are two widespread methodologies: the US one from 2020 and the European one from 2022. Based on these methodologies, CRM lists have been established in the USA and the EU respectively.

Essentially, there is no definition of critical raw materials. There are several versions given/provided by some countries and organizations which deal in detail with this issue, such as the USA, the EU, Australia and Norway. A general definition of CRM describes them as *minerals*, *elements*, *substances* or *materials* of essential importance for economic or national security of a country, whose supply chain is subject to disruptions. These materials are used in energy technologies, defiance, currency, agriculture, consumer electronics and applications related to health protection, while their shortage may threaten national security and safety of a country.

The US methodology is based on the following factors: *economic vulnerability*, *disruption potential*, *trade exposure* and *supply risk*, with all the parameters being between 0 and 1 (Nassar & Fortier, 2021, p. 3). Based on these factors, the USA (USGS), established the methodology and list of CRM in 2020, which was acknowledged in the Energy Act (U. S. Department of Energy). The 2023 CRM list in the USA contains 50 raw materials: aluminium, antimony, arsenic, barite, beryllium, bismuth, cerium, cesium, chromium, tin, cobalt, dysprosium, erbium, europium, fluorite, gadolinium, gallium, germanium, graphite, hafnium, holmium, indium, iridium, lanthanum, lithium, lutetium, magnesium, manganese, neodymium, nickel, niobium, palladium, platinum, praseodymium, rhodium, rubidium, ruthenium, samarium, scandium, tantalum, tellurium, terbium, thulium, titanium, vanadium, wolfram, ytterbium, yttrium, zinc and zirconium.

The EU established its methodology of determining the CRM list in 2020, but it adopted the CRM Act as late as 2024, obliging all the EU member-states to harmonize their respective legislations in the field of mining and related fields with this Act (Blengini et al., 2017, pp. 1–30). The EU methodology uses the following criteria for establishing CRM – *economic importance* (EI ≥ 2,8) and *supply risk* (SR ≥ 1). The EU list encompasses

34 raw materials. The European list contains the labels L&HREE, RE and PGE, which includes more than 20 special raw materials. The European list encompasses: aluminium/bauxite, antimony, arsenic, barite, beryllium, *boron/borates*, *fluorite*, *phosphate rocks* (*from apatite*), *phosphates* (*phosphorites*), *feldspars*, gallium, germanium, *natural graphite*, hafnium, helium, L&HREE, *silicon metal*, cobalt, *coking coal*, lithium, *magnesium*, manganese, niobium, PGE, scandium, strontium, tantalum, titanium, vanadium, bismuth, wolfram.

LREE is a label for Light Rare Earth Elements – lanthanides group: cerium, lanthanum, neodymium, praseodymium and samarium.

HREE is a label for Heavy Rare Earth Elements – lanthanides group: dysprosium, erbium, europium, gadolinium, holmium, lutetium, terbium, thulium, ytterbium, yttrium.

RE is a label for a group of Rare Elements: niobium, tantalum, strontium, zirconium, hafnium, scandium, rhenium, thallium, gallium, cadmium, indium, selenium, tellurium, germanium.

PGE is a label for a platinum group of elements: platinum, palladium, iridium, osmium, rhodium, ruthenium.

Strategic CRM (the EU): boron, gallium, germanium, natural graphite, L & HREE, silicon metal, cobalt, lithium, magnesium, manganese, PGE, titanium, bismuth, wolfram (copper, nickel).

In both methodologies there is a rule that a new list should be established every three years. The first lists were published in 2020, and the last ones in 2023. (Grohol & Veeh, 2023, p. 3). As it can be seen, many mineral resources are present in both lists. Besides these lists, independently of each other, in the past few years the USA has established a separate CRM list in energy. This list includes only some of the raw materials from the main list. After 2022, the EU established a special list called Strategic Critical Raw Materials. That list includes only some of the raw materials from the European list.

The main elements of the CRM Act adopted by the EU (the EC) are as follows:

1. Minimum 10% of the EU's needs for raw materials should be provided from primary production (mining) in the EU territory;
2. Minimum 40% critical raw materials processing should take place in the EU territory;
3. Minimum 15% of the European needs for critical raw materials should come from recycling;
4. Imports of individual CRM from one country should not exceed 65%;
5. Strategic projects aimed at ensuring critical raw materials should have a quick and simple path towards obtaining exploration and mining permits;
6. It is necessary to enable the priority of such projects in terms of financing;
7. Substantial involvement of the EU and support in the realization of such projects;
8. Activation and exploitation of the mines containing critical raw materials even when initiating production has no economic justification;
9. Establishment of monitoring over critical raw materials, defining supply chains

and predicting potential disruptions in the routes and methods of supply;

10. Including national and commercial banks in these processes on a larger scale;
11. Buyers' association in conglomerates with the main purpose of supplying the EU with critical raw materials more quickly and safely;
12. Data exchange among member-states about active locations of mining and flotation waste landfills;
13. Formation of data bases about old mining locations and places where mining and flotation waste is disposed of;
14. Introduction of magnet recycling as a priority.

The largest world producers of CRM are: China (59%), the USA (7%), South Africa (5%), Australia (4%), Chile (4%), Canada (3%), DR Congo (3%), Turkey (3%), Brazil – France – Greece – India – Indonesia – Mexico – Portugal – Russia – Spain – Thailand (1%).

The largest world exporters of CRM are: China: barite (38%), bismuth (49%), cerium (99%), dysprosium (98%), erbium (98%), europium (98%), gadolinium (98%), holmium (98%), thulium (98%), lutetium (98%), ytterbium (98%), lanthanides (99%), magnesium (93%), graphite (47%), neodymium (99%), praseodymium (99%), samarium (99%), terbium (98%), titanium (45%), wolfram (26%), yttrium (98%).

Africa: bauxite (64%), cobalt (68%), phosphate rocks (24%), tantalum (36%).

South America: fluorite (25%), lithium (78%), niobium (85%).

Asia: natural rubber (31%), phosphates (71%).

Australia: coking coal (24%) (Blengini et al., 2020, p. 9).

Serbia, mineral resources and critical raw materials

In the territory of Serbia, exploration and exploitation of raw materials in recent history have lasted uninterruptedly since 1835. That is when Baron Sigmund August Wolfgang Herder came to Serbia at the invitation of Prince Miloš, in order to "make use of the mining wealth for the sake of Serbian fatherland". At the end of 1848, exploration works and iron exploitation began in Majdanpek, Rudna Glava and Crnajka. To date, the following raw materials have been explored in our country, from the level of ore occurrences to deposits:

Metallic raw materials: lead-zinc, copper, gold, antimony, tin, iron, manganese, wolfram, chromium, nickel-cobalt, molybdenum, bauxite, mercury, REE, PGE, lithium, bismuth, titanium (Geodetic Institute, group of authors, 1999, pp. 1–240; Jelenković, Mijatović, 2006–2010).

Non-metallic raw materials: magnesite, dunite, chrysotile asbestos, refractory/ceramic/ kaolin clays, aluminosilicates, feldspars, quartz sand, quartz raw materials, bentonites, zeolite, diatomites, limestone, dolomite, barite, fluorite, boron, phosphorite, anhydrite, talcum, wollastonite, vermiculite, micas, jewellery raw materials, graphite (Geodetic Institute, group of authors, 1999, pp. 1–240; Jelenković, Mijatović, 2006–2010).

Energy raw materials: coals (stone, brown, lignite), oil shales, *uranium*, oil and gas (Geodetic Institute, group of authors, 1999, pp. 1–240; Jelenković, Mijatović, 2006–2010).

From this short review, it can be clearly seen that the geological explorations to date have registered numerous mineral resources which are nowadays treated as CRM in Europe and worldwide. According to the EU methodology and list of CRM, the following raw materials have been registered in Serbia: *copper, antimony, manganese, wolfram, nickel-cobalt, titanium, bauxite, L&HREE, PGE, lithium, magnesite, feldspars, barite, fluorite, boron, phosphorite, graphite, arsenic, bismuth.*

In technogenic/secondary deposits (tailings), after processing lead-zinc and copper ores, significant content of the following elements has been registered: *scandium, indium, gallium* (RE), *L & HREE.*

Global demand for CRM and other metals by materials for pure energy technologies according to STEPS and SDS scenario

According to STEPS, the current assessment (STEPS) of the EU's needs for metallic raw materials until 2050 is 45 million tons. According to the dynamic assessment of the needs for metallic raw materials (SDS) in the EU (aluminium, copper, nickel, zinc, lead, silicon, lithium, manganese, chromium, cobalt ...) until 2050 is 75 million tons. The OECD assessment shows that the global demand for raw materials will increase from the current amount of 79 million tons to 167 million tons until 2060.

The assessment of the percentage increase in the needs for metals until 2050 for pure energy technologies as compared to the general use in 2020 (global SDS ambitious climate scenario) is as follows (CRM + other metals):

Table 1. Assessment of the percentage increase in the needs for metals until 2050

Raw material	Percentage increase	Raw material	Percentage increase
Lithium (Li)	2.109%	Silicon (Si)	62%
Dysprosium (Dy)	433%	Terbium (Tb)	62%
Cobalt (Co)	403%	Copper (Cu)	51%
Tellurium (Te)	277%	Aluminium (Al)	43%
Scandium (Sc)	204%	Tin (Sn)	28%
Nickel (Ni)	168%	Germanium (Ge)	24%
Praseodymium (Pr)	110%	Molybdenum (Mo)	22%
Gallium (Ga)	77%	Lead (Pb)	22%
Neodymium (Nd)	66%	Indium (In)	17%
Platinum (Pt)	64%	Zinc (Zn)	14%
Iridium (Ir)	63%	Silver (Ag)	10%

Source: KU Leuven, 2022: Metals for clean energy: Pathways to solving Europe's raw materials challenge

The assessment of the increasing demand in the EU for metals necessary in the development of pure energy technologies:

Table 2. Electric vehicles (without batteries and permanent magnets)

Demand (kt)		Base metals	Other metals
In 2020	In 2050	Al, Cu, Pb, Zn, Si	B, Ag, Ga, Pt, Au, Ge, In
482	5.356		

Source: KU Leuven, 2022: Metals for clean energy: Pathways to solving Europe's raw materials challenge

Table 3. Batteries for electric vehicles

Demand (kt)		Base metals	Other metals
In 2020	In 2050	Ni, Li, Si, Co, Mn	Al, Cu
34	1.287		

Source: KU Leuven, 2022: Metals for clean energy: Pathways to solving Europe's raw materials

Table 4. Solar panels (photovoltaic)

Demand (kt)		Base metals	Other metals
In 2020	In 2050	Al, Zn, Cu, Si	Sn, Pb, Ag, Ni, Te, Cd, In, Ga, Ge
0	697		

Source: KU Leuven, 2022: Metals for clean energy: Pathways to solving Europe's raw materials challenge

Table 5. Wind turbines

Demand (kt)		Base metals	Other metals
In 2020	In 2050	Cu, Al, Mn, Cr, Ni	Zn, Mo, B
75	206		

Source: KU Leuven, 2022: Metals for clean energy: Pathways to solving Europe's raw materials challenge

Table 6. Hydrogen (technologies)

Demand (kt)		Base metals	Other metals
In 2020	In 2050	Ni, Cu, Cr, Al, Zn	Mn, Sc, Co, Ir, Pt
0	3,95		

Source: KU Leuven, 2022: Metals for clean energy: Pathways to solving Europe's raw materials challenge

Table 7. Permanent magnets

Demand (kt)		Base metals	Other metals
In 2020	In 2050	Nd, Pr, Dy	Tb
0	2,67		

Source: KU Leuven, 2022: Metals for clean energy: Pathways to solving Europe's raw materials challenge

Table 8. Electric power grid

Demand (kt)		Base metals	Other metals
In 2020	In 2050	Al, Cu, Zn	
297	511		

Source: KU Leuven, 2022: Metals for clean energy: Pathways to solving Europe's raw materials challenge

Lithium

Lithium (Greek Λίθος – stone) has symbol Li and atomic number 3 on Mendeleev's Periodic Table, while it is the lightest of all known metals. Its atomic weight is 6.94 and specific density 0.534 g/cm^3 (at the temperature of 20°C).

It is composed of two lithium isotopes – ^{7}Li (92.6%) and ^{6}Li (7.4%) and belongs to the group of alkali metals. Lithium is a very light metal and has the lowest density of all solid elements (in standard conditions).

The history of lithium began around 1800, when famous Brazilian statesman, geologist, natural scientist and poet José Bonifácio de Andrada e Silva discovered and described the mineral petalite (LiAlSi4O10) in the rock samples from the island of Utö, Sweden. Lithium was discovered by Johan Arfwedson in 1817. Berzelius, his university mentor, suggested the name for the new material – lithion. Many years later, pure lithium was obtained by the lithium-oxide electrolysis procedure, while larger amounts of lithium were obtained from lithium-chlorine in the middle of the 19th century. Intensive lithium production began in Germany in 1923 through the electrolysis of molten mixture of lithium chloride (LiCl) and potassium chloride (KCl). Until the end of the Second World War, lithium was used solely as a machine lubricant and in glass industry. Real expansion of the demand for lithium occurred in the USA after the Second World War. That is when the US scientists working on the development and improvement of the hydrogen bomb, while looking for tritium, managed to obtain it by separating it from lithium through ^{6}Li neutron activation in the nuclear reactor.

Due to its geochemical characteristics and great reactivity, lithium is found in its elementary state in nature. When in its elementary state, it is kept in kerosene or some other mineral oil. In dry air it becomes lithium nitride, while in damp air it turns into lithium hydroxide. In the form of various salts, it is found in mineral waters.

In nature, lithium participates in the building of a series of minerals. Some of them are base ores in the processing of which lithium carbonate is obtained, as follows:

- spodumene,
- petalite,
- lepidolite,
- zinnwaldite,
- amblygonite,
- jadarite,
- hectorite,
- zabuyelite.

The main source of lithium from rocks is the mineral spodumene from the group of pyroxenes, built from lithium inosilicate. Essentially, it is a petrogenic mineral which builds different types of rocks, including pegmatites. In the course of lithium exploitation from pegmatites, first a spodumene concentrate is obtained, and then, in the technological procedure, lithium carbonate is obtained. Spodumene in pegmatites is found together with the minerals with lithium, such as petalite and amblygonite, but they are largely subordinate.

A special type of the mineral lithium is zabuyelite, which is a natural lithium carbonate (not artificially produced). It was discovered in 1987 in

Tibet – in Lake Zabuye, after which it was named, while its exploitation began in 2004/2005.

Particularly outstanding in the list of minerals from which lithium is obtained are jadarite and hectorite. Apart from jadarite, hectorite and zabuyelite, above-listed minerals are present in the composition of pegmatites as petrogenic minerals, while pegmatites are the final phases of differentiation and solidification of granitic melt when there is an increased content of water enriched with fluorine and lithium. Jadarite is a new mineral discovered in the samples from the exploration wells in the Jadar River Valley near Loznica, in the layers of ore body drilled in 2004. Since 2004 to date, the same mineral

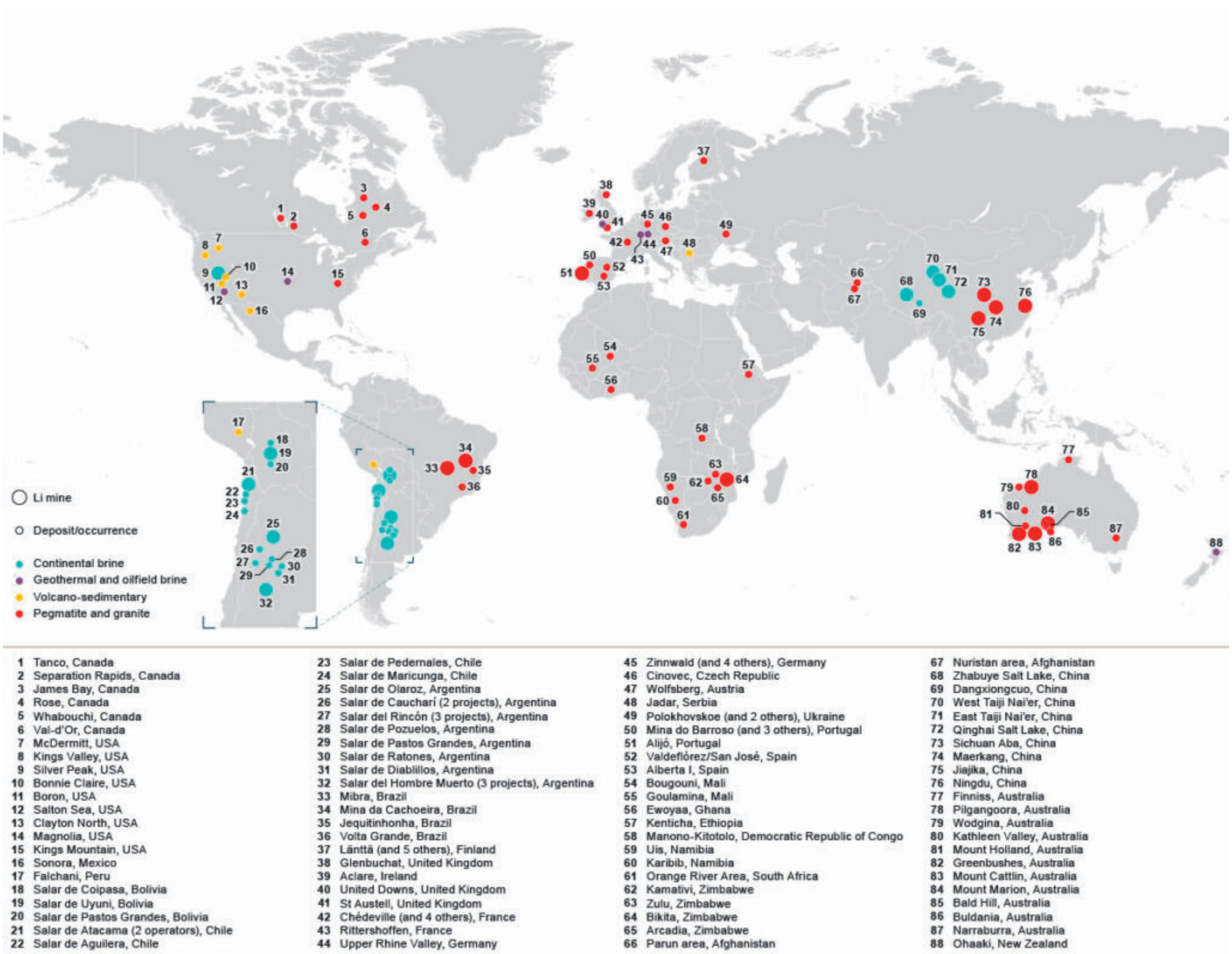

Figure 1. Map of the distribution of lithium mines, deposits and occurrences in the world
Source: Shaw, 2021

has not been registered anywhere else in the world. The mineral hectorite is the main component of white greasy clays created by the decomposition of granitoids (rhyolite pegmatites). Future exploitation of lithium from the mineral zinnwaldite, is planned in the Federal Republic of Germany. Zinnwaldite is a silicate mineral from the group of micas, and by its composition it is potassium-lithium-iron-aluminium-silicate-hydroxide fluoride. Lepidolite is also a silicate mineral and a secondary source of lithium, occurring together with spodumene. It is of greatest importance for the production of rubidium.

Lithium exploration is in full swing throughout the world – in Australia, China, the USA, Argentina, Chile, Bolivia, Portugal, Germany, Czech Republic, Finland, Great Britain, France, Norway, India and Serbia. There are several reasons for geological exploration of lithium: first, the lack of lithium in the market (demand greater than offer), then the development of new technologies, implementation of agendas for "green energy" and "decarbonization", wide application in different branches of industry, and categorizing lithium among CRM.

In November 2021, BGS presented the world map with the list of all the lithium deposits and occurrences (Shaw, 2021). The list contains 88 locations/toponyms with different statuses: occurrences currently explored, deposits with completed explorations and without exploitation, and deposits in the process of exploitation.

The distribution by continents is as follows:

- **North America:** 15 locations are shown, whereas only lithium is exploited in just one location. In the deposit in Silver Peak (the USA) lithium is obtained from salt solutions by pumping about four billion gallons of water (US gallon = 3.785 l) from the underground, or 15.14 billion litres of water, every year since 2020. The annual production is about 6,800 t of lithium. In other locations, either intensive exploration is performed or lithium is just one of the raw materials being exploited (Nb, Ta and others).
- **Central America:** The project Sonora is under development in Mexico, and there are no other projects.
- **South America:** 20 locations are being actively explored. Four deposits are exploited from salt groundwater and two deposits are exploited from pegmatites. Lithium is exploited from salt water in Saler de Uyunu – Bolivia, Saler de Atacama – Chile, Saler de Olaroz – Argentina, and Saler de Hombre Muerto – Argentina. Lithium is exploited through surface exploitation of pegmatites in Mibra – Brazil and, apart from lithium, tantalum and niobium are also obtained. In the underground exploitation of spodumene, lithium is exploited from pegmatites in Mina da Cachoeira, Brazil.
- **Africa:** lithium is explored at 12 locations, while surface exploitation is performed in the mine Bikita – Zimbabwe, where spodumene and petalite are exploited and lithium is obtained from them.
- **Asia:** intensive exploration at three locations. Exploitation is performed in four places from salt groundwater and in four places from pegmatites. Exploitation from salt water is performed in several salt lakes in China: Zabuye Salt Lake, West Taiji Nai'er, East Taiji Nai'er and Qinghai Salt Lake. Exploitation from pegmatite is performed at four locations in China: Sichuan Abe, Maerkang (surface exploitation from pegmatites – spodumene), Jiajika (surface exploitation from albite-spodumene

pegmatites with lithium, while beryllium, niobium, tantalum and cesium(caesium), Ningdu (open pit granite-pegmatite mine) are also obtained.

- **Australia:** there are four active mines with surface exploitation. The active mines are: Pilgangoora (surface open-mine in pegmatites, where lepidolite, spodumene, tantalite, cassiterite and small amounts of microlith, tapiolite and beryl are exploited; Li + Ta products), Greenbushes (open-pit mine of pegmatite with spodumene, the biggest world mine of Li in pegmatites), Mount Cattlin (open-pit mine, pegmatites with spodumene), Mount Marion (open-pit mine, pegmatites with spodumene).

In Europe, lithium is exploited only in one place – form the deposit Alijo in Portugal, from the mineral spodumene. There is intensive geological exploration of all raw materials from the CRM list in Europe. Out of numerous locations in Europe where lithium is explored, the exploration is in its final phases at 21 locations. Exploration works and accompanying studies have progressed furthest at the following locations:

- *Mines in the exploration phase*: Goncalo – Alvaroso, Bajoca – La Fregeneda, Goncalo – Castanho, all the locations in Portugal (Filippov, Filippova, 2023);
- *Projects in development (feasibility study preparation)*: Central Ostrobothnia (Keliber) – Finland, Zinnwald – Germany (Filippov, Filippova, 2023);
- *Projects with a feasibility study*: Cinovec – Czech Republic, Wolfsberg – Austria, Mina do Barroso, Romano Sepeda, Argemela – Portugal, San Jose – Spain, Emili – France (Filippov, Filippova, 2023), Serbia – Jadar (Faculty of Mining and Geology, 2021);
- *Projects in the pre-feasibility study phase*: Sadisdorf – Germany, Presqueiras – Spain (Filippov, Filippova, 2023);
- *Projects attractive for continued research/work*: Adagoi, Alijo – Portugal, Hirvikallio, Kietyönmäki – Finland, Bergby, Varuträsk – Sweden, NW Leinster – Ireland (Filippov, Filippova, 2023);

The European Union has directly supported the following projects: Goncalo-Alvaroso, Mina do Barroso – Portugal, Central Ostrobothnia (Keliber) – Finland, Emili – France (Filippov, Filippova, 2023).

The largest lithium (metal) reserves in the world are located in the following countries:

1. Bolivia – 23 million tons,
2. Argentina – 22 million tons,
3. Chile – 11 million tons,
4. Australia – 8.7 million tons,
5. China – 6.8 million tons,
6. Germany – 3.8 million tons,
7. DR Congo – 3 million tons,
8. Canada – 3 million tons,
9. Mexico – 1.7 million tons,
10. Czech Republic – 1.3 million tons,
11. *Serbia – 1.2 million tons*,
12. Peru – one million tons,
13. Russia – one million tons,
14. Mali – 890,000 tons,
15. Brazil – 800,000 tons,
16. Zimbabwe – 690,000 tons,
17. Spain – 320,000 tons,
18. Portugal – 270,000 tons,

19. Namibia – 230,000 tons,
20. Ghana – 200,000 tons,
21. Finland – 68,000 tons,
22. Austria – 60,000 tons,
23. Kazakhstan – 50,000 tons (USGS, 2024).

Today, lithium is obtained on the largest scale by exploitation from continental highly-mineralized salt waters (Chile, Argentina, Bolivia, China, the USA); then by processing minerals spodumene and lepidolite (with the accompanying pegmatite minerals). Very small amounts, in the experimental phase, are obtained from hectorite in Cornwall, partly also within the future deposit in McDermitt, USA. In the near future, after the completion of exploration and the beginning of exploitation, lithium will also be obtained from geothermal waters and salt waters in oil drills (Magnolia in the USA, the Rhine River valley in Germany, United Downs in the UK), from volcanogenic-sedimentary deposits (Jadar in Serbia; McDermitt, Kings Valley, Bonnie Claire, Boron, Clayton North, Kings Mountain in the USA, and Falchani in Peru). With the beginning of exploitation in the Czech Republic (Cinovec) and Germany (Zinnwald) lithium carbonate will be obtained from the mineral zinnwaldite. Only in China natural lithium carbonate is exploited from the salt lake waters in Tibet in the form of the mineral zabuyelite.

The biggest world producers of lithium in the period 2021–2023 are shown in Table 9.

Table 9. Lithium production in the world

Producing countries	Production in the world (t)		
	In 2021	In 2022	In 2023
Australia	55,000	61,000	86,000
Chile	28,300	39,000	44,000
China	14,000	19,000	33,000
Argentina	5,970	6,200	9,600
Brazil	1,700	2,200	4,900
Zimbabwe	710	800	3,400
Canada	/	500	3,400
Portugal	900	600	380
Other countries	/	/	3,700

Source: STATISTA; USGS, 2024

Three biggest world producers of lithium carbonate and lithium hydroxide are Australia, Chile and China, which cover 90% of the world's market, while Argentina, Brazil, Zimbabwe, Portugal and Canada account for 9.5%, and all other countries having the remaining share in the world's production. The biggest producer of lithium in Europe is Portugal.

Generally speaking, according to the statistical data, lithium production in 2023 amounted to about 188,000 t, while the world-level demand was about 980,000 t. In 2025, lithium demand will exceed one million tons, and by 2030 it will exceed two million tons. At the same time, it is estimated that lithium production in 2025 will reach the amount of about 500,000 t, which can by no means fulfil the needs of world economy. The needs for lithium will continue to increase and in 2050 demand for this metal will reach about 3,500,000 t (all data have been taken from German specialized website STATISTA). The discrepancy between lithium offer and demand is not surprising when we take into account its multiple uses: batteries – 87%; ceramics and glass – 4%; lubricants – 2%; air treatment – 1%; flux powders for continual flux powders for continuous casting moulds – 1%; medicine – 1%; and other uses (production of aluminium, special types of rubber, pharmacy, cosmetics, electronics) – 4%.

The growing lithium market has been accompanied by the instability of its price in the past two years. After the significant increase at the beginning of 2022, the price of lithium began fluctuating due to the changes in stock. In 2022, the supplies of lithium-based products which were necessary for battery production were reduced, but in 2023 they began increasing, both due to the growing offer of the existing producers, and due to the new participants in their production. One of the reasons for the decrease in the lithium prices in the world's market is also the discontinuation of government subsidies in 2022 in PR China and FR Germany for the purchase of electric vehicles. The trends of lithium prices at the world level and their projection until 2030 are shown in the following figure:

Year	Price range projection	Key factors
2024	LITHIUM HYDROXIDE: $12.775 LITHIUM CARBONATE: $9.856,55 TO $15.500	• INCREASING ACCEPTANCE OF ELECTRIC VEHICLES • SLOWER SALE OF ELECTRIC VEHICLES • BATTERY CAPACITY SURPLUS IN CHINA
2025	LITHIUM HYDROXIDE: $13.485/T LITHIUM CARBONATE: $9.411,15/T TO $20.000/T	• CONSTANT EXCESSIVE SUPPLY • INCREASING DEMAND FOR ELECTRIC VEHICLES • USA AND CHINA TRADE WAR
2026-2030	LITHIUM HYDROXIDE: 2026: $14.775 LITHIUM CARBONATE: 2026: $12.000 2027: $14.000	• ENERGY TRANSITION • DEMAND EXCEEDS SUPPLY • APPEARANCE OF ALTERNATIVE BATTERY SOURCES

Figure 2. Comparative projection of the price of lithium hydroxide and lithium carbonate

Source: Techopedia

It is predicted that the prices of raw materials for the production of batteries will remain higher because of the expected offer growth, challenges and costs related to production etc. Most capacities for lithium exploitation were concentrated in Chilean salt pans and lithium hard-rock deposits in Australia (spodumene mines). China has a dominant position in the processing of lithium ore.

Average prices of lithium carbonate, lithium hydroxide and spodumene today as compared to January 2024 are as follows:

- lithium carbonate – US$ 10,934 per ton (January: US$ 11.867);
- lithium hydroxide – US$ 9,563 per ton (January: US$ 9.899)
- spodumene – US$ 990 per ton (January: US$ 1,000)

According to the data of the company Rio Sava (Elaborate on the reserves from 2020), the production of jadarite ore from the deposits should be maintained at 1.8 Mt/g, while the production of lithium carbonate should be maintained at 58,000 t/g

(Misailović, Tanasković, 2020). When this is compared with the production from the previous table, Serbia would have the second place in the world by the production of lithium carbonate. From the quantity of proven reserves, only the jadarite deposit belongs to the category of large deposits. Proven reserves are 158,647,256 tons. The exploitation period is predicted to be longer than 60 years. After analyzing the available data about the planned activities in geology and mining in the EU territory, future exploitation of lithium from European deposits, market needs and investments in industry using lithium, and exploitation plans, it can be concluded that Serbia will be at the very top of European exploitation of lithium ore and lithium-based industry. According to the predicted production, as it has already been stated, Rio Sava is planning the annual production of 58,000 tons of lithium carbonate. The estimates of the future production of LCE (lithium carbonate equivalent) in Europe are presented in the following table:

Table 10. Predicted production of lithium carbonate in the EU

No.	Producing country	Lithium carbonate (t)
1.	Serbia	58.000
2.	Germany	42.000
3.	Czech Republic	30.000
4.	UK	28.000
5.	Portugal	20.000
6.	Finland	20.000
7.	Spain	15.000
8.	Austria	9.000

The review of price trends per ton of lithium carbonate in the Chinese yuan (1 yuan = US$ 0,14), in the world's market is presented in the following chart:

Chart 1. Price trends of lithium carbonate (2020–2025)

Source: Trading Economics

According to some estimates of the share of LCE from Jadar in the needs of Serbian and European industry using lithium carbonate, Rio Sava would fulfil almost 50% of the needs. This is essentially the assessment of the conditions in the market until 2030, provided that the deposit in the Jadar Valley remains in function. All European and world statistics regarding lithium emphasize great demand for lithium/lithium carbonate, and the production cannot keep pace with such demand. That is why lately intensive geological exploration has been performed and there is an attempt to turn as many exploration projects as possible into exploitation projects. According to the assessments by Western analysts, in order to stabilize the market of lithium/lithium carbonate until 2040, in the period until 2040 it is necessary to open another 60 more lithium mines worldwide which would be of the same size as the Jadar mine,

The assessments have been made of the effects of mine opening and operating in the Jadar Valley for Serbian economy. The first effects would be shown in Rio Tinto's investment in the mine opening project. According to the data from the Elaborate on reserves, the investment in the preparation of underground mining facilities and surface mining infrastructure with the production section intended for obtaining lithium concentrate, boric acid and sodium sulphate, and with the waste treatment system, would amount to about two billion Euros (Misailović, Tanasković, 2020). In the phase of ore exploitation and processing to final products, as many as 2,000 more workers would be employed, both with high qualifications and with no qualifications. This should also take into account the engagement of external service activities outside the mine and processing system. As for the effects regarding Serbia's budget, several options or scenarios have been considered:

1. LCE production and market placement, according to the estimates, would account for only about 0.95% of GDP;
2. Production of LCE and cathodes and their placement in the market, according to the estimates, would account for about 2.06% of GDP;
3. Previous complete production and batteries, according to the estimates, would account for about 3.97% of GDP;
4. Production from previous options and electric vehicles, according to the estimates, would account for about 16.45% of GDP.

If we take into account such development of the situation at the economic level on the one hand, and the intensification of interments into our mining sector (government, domestic and foreign capital) through different forms of investing, on the other hand, GDP might be increased on a large scale. For all this there are real prospects, particularly taking into account the prepared Master Plan for Mining in Serbia, which was financed by the World Bank (Nishikawa, 2008). The Master Plan was prepared by the Japanese company JICA in 2008 and it assessed that mining in Serbia had realistic foundations to participate in GDP with about 16%.

Economic effects of lithium exploitation can be monitored in the following example from Australia. The figure below shows the value of lithium in Australia and in the world after extraction and different levels of processing. The total value of lithium ore accounts only for about 1% of the total value of the end product. Approximately 99.5% of

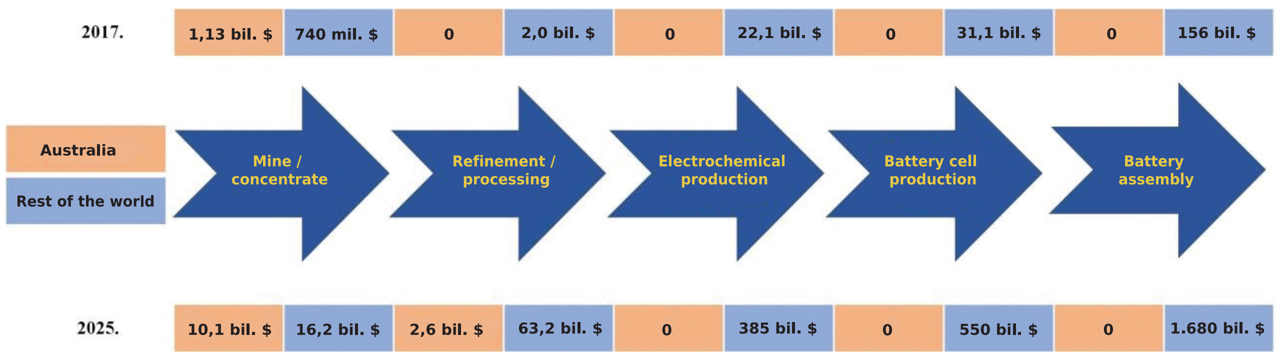

Figure 3. Value of lithium in Australia and the world depending on the degree of refinement and use
Source: Capturing the value of the global lithium supply chain. Innovation Newsnetwork

the value of Australian lithium ore is added through its processing at the sea, through production of cells and assembly of batteries.

Conclusion

The issue of CRM, in particular of lithium as one of very important raw materials from the CRM list, has been dealt with in the main segments in this paper. There is a descriptive definition of CRM and the methodologies on the basis of which they are determined. At the end of the first part of the paper, which deals with CRM, there is an overview of raw materials in Serbia, as well as the list of raw materials explored in Serbia and included in the EU's list of CRM.

The second part of the paper deals with lithium, currently one of the most demanded metals in world's economy. It is necessary in many branches of industry and, at the global level, there is a huge demand for its main product - lithium carbonate, which has multiple application. Currently, the demand for lithium substantially exceeds its offer in the market. That is the main reason for intense geological explorations by the most powerful mining companies worldwide, i.e., on all continents. On the other hand, many countries in whose territories new deposits can be expected see an opportunity for their economic stability, progress, adoption and development of new technologies.

All CRM from the European list that can be found in Serbia, in particular lithium, are the country's important resource for the development of new technologies aimed at implementing the policy of climate neutrality and decarbonization until 2050, which is defined by the Integrated National Energy and Climate Plan of the Republic of Serbia for the period until 2030, with a vision until 2050.

The final part of the paper presents Serbia's possibilities regarding the development of the mines of jadarite (lithium) in the Jadar Valley and shows potential financial effects on Serbia's GDP.

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Mining in Medieval Serbia

Abstract: Mining, also known as *Montanindustrie*, in the territory of medieval Serbia had a long road of development, from surface mining to dizzying achievements which began with the arrival of the Old Saxons in the 13th century. Thanks to their influence, or the combination of technological development and available raw materials, Serbia underwent a general economic rise and as early as the first half of the 15th century it accounted for the production of one quarter or one fifth of silver in Europe. However, the Old Saxon influence was not limited only to mining, but it also included the development of mining towns, as well as craft industry. That is why this paper elaborates on the development of mining in the territory of medieval Serbia from its settlement until its fall under the Ottoman rule, with the aim of exploring long-term processes which substantially affected the change not only in the economy, but in society as well.

Keywords: economy, mining, Old Saxons, Serbia, Middle Ages/medieval, international initiatives

Introduction

It is never simple to study the development of a single branch of economy because it is long-lasting phenomenon which, although it may be explored by segments or periods, still entails the exploration of sets of important factors, both the basic ones (resources, means of work, workforce, technological progress) and the specific ones (territory, population, social organization, epoch, influences). A particular problem in studying a branch of economy during an epoch, particularly in earlier periods, is the fact that its development is not fully subject to the application of the modern economic theory. Therefore, regarding the research of mining in the territory of medieval Serbia we must first address economic history, according to which it is one of the five existing medieval industries.[2]

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[2] The other four are: household, rural, town and developed trade.

It must be further upgraded by the partial application of the economic sectors theory, according to which mining belongs both to the primary and secondary sectors, i.e., both to the extraction and primary processing of raw materials. In the end, mining must also be observed from the perspective of its relationship with other types of industry and production, as well as in its correlation with the above-mentioned basic and specific factors (Fostikov, 2019, pp. 9–10, 30).

Accordingly, before we point to the general directions of development, as well as the changes in that development and the effect of mining itself on the development of general economy and society, we must emphasize several especially important facts. Apart from the population-territory-language relationship which is relevant for marking the chronological period as the time from the settlement of the Slavs to the fall of the Serbian state under the Ottoman rule – or the territories considered Serbian in that period (the borders of King Milutin's state, 1282–1321, expanded in the north by the borders from the time of the Serbian Despotate, 1402–1459) – as one of the most important factors, we must emphasize the arrival of the Old Saxon miners in the 13^{th} century as indisputably related to rapid technological progress that will lead to Serbia, rich in mineral resources, to become not only economically strong, but also to produce one quarter or one fifth of Europe's silver. Moreover, the arrival of the Old Saxons, together with the rise of mining, led to the further urbanization thanks to the foundation of mining towns (*montans*)[3] that, at the same time, became the most important economic centres, in which trading colonies were established and crafts flourished.[4] These towns attracted an increasing number of inhabitants and became more densely populated, just as the mining regions themselves, but at the same time they also became isolated islands subject to a special code which regulated the operation of the mines and the economic and social life of the urban centres based on the so-called Saxon *pravice*, or acquired rights/privileges (Fostikov, 2019, pp. 9–10; Fostikov, 2021, pp. 153–158).

As one of the most important factors, we must emphasize the arrival of the Old Saxon miners in the 13^{th} century as indisputably related to rapid technological progress that will lead to Serbia, rich in mineral resources, to become not only economically strong, but also to produce one quarter or one fifth of Europe's silver.

Finally, when speaking of the chronological development of mining, it is necessary to point out that in the territory of medieval Serbia it covered a long road of development, from surface mining to dizzying achievements in the period from the 13^{th} to the 15 century, and then, after the eventual fall of Serbia under the Ottoman rule, it dwindled for a short of period of time, only to fall

[3] The word "montan" is adopted in historiography as e term denoting mining settlements subject to Old Saxon acquired rights or privileges (pravice). The word "montan" comes from the name for medieval mining industry, or *Montanindustrie.*

[4] The rise of metallurgy contributed to the better quality of weapons and tools, including the agricultural tools.

completely into oblivion, even in the folk tradition, after the shifting of home territories from the south to the north after the middle of the 17th century (Ćirković, Kovačević-Kojić, Ćuk, 2002, pp. 5–6).

However, despite the importance of mining for medieval Serbia, it was long on the margins of the researchers' interest, just as many other topics. After the first steps undertaken by Konstantin Jiriček and then by Stojan Novaković in the last third of the 19th century, it became the research topic once again as late as the middle of the 20th century. Numerous papers on mining were written by Mihailo Dinić and Vasilije Simić, as well as Sima Ćirković, Desanka Kovačević Kojić and Ruža Ćuk, who compiled a monograph with that topic at the beginning of the 21st century (Ćirković et al., 2002). At the same time, more detailed research of mining began within archaeology, led by Dušan Mrkobrada (Vranić, 2021, pp. 726–727). In the younger generation of researchers of Serbian medieval mining, Vladeta Petrović has paid special attention to certain matters, while Srđan Katić has dealt with Ottoman mining which is, in many ways, not only the continuation, but also the legacy of medieval mining.[5] Further archaeological research of this period is conducted by M. Vranić.[6] Slightly more papers written during the 20th and the 21st centuries are dedicated to the Old Saxons as well, the question which in itself intrigued numerous researchers. However, that question alone has never been explored in detail, except from the perspective of crafts (Fostikov, 2021). In addition, since the discovery of Despot Stefan's Mining Code, which had many Cyrillic editions (Radojčić, 1962; Marković, 1985) and one Latin edition (Ćirković, 2005), several authors have dealt with it, while more serious comparison-based research of this Code is yet to be conducted (Katančević, 2022; Katić, 2024; Fostikov and Rokai, in the process of preparation). In line with the fact that mining is just one branch of economy and, thus, a comprehensive and broad topic, here we will try to point to the most important features of its development and to look briefly at the most significant factors, as well as the processes and phenomena affected by mining in return.

Development of mining from the settlement in the Balkans to the arrival of the Old Saxons

There are no preserved written data about mining in the Balkans after the period of the settlement of the Slavs, which would give us a precise picture about the use of raw materials, their primary processing or the course of the process. However, based on the facts that, after their arrival in the territory of the Balkans, the Slavs found the remnants of ancient mining, as well as that they already had Slav terms for extraction and primary processing

[5] To avoid encumbering the text by listing all the papers by these authors, we will point out that all those papers, including the ones quoted below, are available online in the Repository of the Institute of History in Belgrade.

[6] M. Vranić is currently completing the doctoral dissertation on the topic "Mining and Metallurgy in Medieval Serbia: Archaeological Findings"; he is also one of the archaeologists who cooperate on the currently ongoing research into the mining in Brskovo and Rudnik.

(ore, hole, heap, pit), and those referring to metalworking, both of precious and other metals, in the broadest meaning (blacksmith, goldsmith), and that they definitely manufactured weapons and tools containing metal components, they must have used the deposits they found, at least the surface ones (Ćirković et al., 2002; Fostikov, 2019). Accordingly, some more data about mining industry in the early Middle Ages will certainly be provided at least by systematic archaeological research.

The Old Saxons and their influence on the development of mining

In contrast to the missing information about mining and metallurgy during and after the settlement period, even during the reign of the first Nemanjić rulers, the development of this branch of economy in the territory of medieval Serbia can be followed in continuity from the first half of the 13^{th} century to the disappearance of Serbian statehood, thanks to both written and archaeological data. The beginning of that period was marked by new mining vigour, which spread from Central to Southeast Europe. The main carriers of that zest were mining experts, in this part of Europe known as the Old Saxons. Although it was long considered that those were experts of ethnic German origin or even directly Saxons, these groups were in fact composed of different ethnoses and, since a number of those settlers, first recorded under that name in the territory of Hungary back in 1206, were Germans/Saxons, this term is common in the broader territory of Hungary and Southeast Europe. In other parts of Europe, these mining experts are also mentioned under the names of *Flandrenses*, *Teutonic*, *Saxones*, or *Latins* (Fostikov, 2021, pp. 153–155).

The germs of the knowledge they spread, as it can be concluded from the written sources, both narrative and those from the sphere of legislation, they essentially owe their roots to Roman mining knowledge and law, on which the German terminology was built, in line with the fact that Roman mining persisted in some parts of Central Europe with German inhabitants. It was on these foundations that mining further developed, and with time, mining technology itself evolved based on the experience. Therefore, the Old Saxons brought new technologies and techniques, such as the skill of digging deep trenches and the method of melting and processing ores. Among them there were also the representatives of metallurgy and other crafts and, since the main terminology was based on the German language, their arrival also brought the Germanisation of local languages, which first adopted the terms referring to mining, and then the names of individual crafts, as the accompanying infrastructure. Therefore, very early, the medieval version of the Serbian language integrated, among others, the terms: tailor, shoe-maker and bag-maker (Pfeifer, 2002; Szende, 2019; Fostikov, 2021).

Although today it is not known when exactly the Old Saxons reached the territory of medieval Serbia, it certainly must have been at least several decades before the first mention of their name in the toponyms listed in the charter of Stefan Uroš I (about 1252–1254). They arrived in these territories most probably through Transylvania and the region of seven chieftains, at least in part, although it is also possible that they arrived directly from Spisz (Zips) in northern Hungary. According to the research to date, the beginnings of their activities in the territory of Serbia are related to Brskovo. During the dizzyingly rapid development of mining in the territory of medieval Serbia, the term "Old Saxon" was no longer merely an ethnic category, conditionally speaking, but it soon entered the legal terminology and became a synonym for the "miner" by the middle 14th century at the latest (Gogić, 2010; Fostikov, 2021, pp. 155–157).

However, despite the importance of the Old Saxons, or of these groups of mining and metallurgy experts, the mapping of their influence on mining, i.e., on general economic or social development of the medieval territories in Europe's medieval frameworks, or the establishing of similarities and differences of the Old Saxon influence in the territory of Southeast and Central Europe, as well as East Central Europe, have not been explored in detail yet, especially not on the basis of comparison, so that new results may be expected in that respect.

Mining from the 13th century to the fall of the Serbian state under the Ottoman rule

After the arrival of the Old Saxons and revival of mining production and the rise of this branch of economy in the territory of medieval Serbia, mining developed uninterruptedly until the fall of this territory under the Ottoman rule. In the first stage of development, during the 13th century and the rise of Brskovo and Rudnik, the number of the newly-opened mines constantly increased. Namely, the first half of the 14th century in the territory of Serbia witnessed the operation of the mines of Novo Brdo, Janjevo, Gračanica, Trepča, Koporići, Belasica, Plana, Zaplanina, Kovači, Livađe, Rogozna, Gluhavica, Kučevo, Lipnik and Trešnjica; in the second half of the 14th century: Srebrenica, Crnča, Bohorina, Ostraća and Kratovo and, in Bosnia: Olovo, Kamenica, Kreševo, Fojnica and Busovača; in the first half of the 15th century, there were as many as 25 active mines, including the newly-opened ones: Rudišta, Krupanj and Zajača in Serbia, and Dusina and Deževica in Bosnia. After the fall under the Ottoman rule, this number first dropped to only fifteen mines, while in the 16th century only seven of them remained active. All of them were situated in several mining basis, particularly the basins of Rudnik, Kopaonik, Novo Brdo and Podrinje. On the whole, it is known that at the time of the most intensive mining activity, there were as many as 43 active mines in the territory of medieval Serbia and Bosnia (Ćirković et al., 2002; Vranić, 2021, p. 724).[7]

According to the descriptions of travel writers, the mineral resources of Serbia, particularly of precious metals, were enormous. As early as 1308 there were already seven silver mines, while in 1332 five gold mines were recorded, including several others where electrum, a natural alloy of silver and gold was extracted (Ćirković et al., 2002, 33). That precious metal mining was really at a high level is indicated by the data establishing that in the first

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[7] Having in mind that the majority of these mines and surrounding settlements is well known in the literature, and in greatest part listed in the *Lexicon of towns and market places in the medieval Serbian lands*, with the overview of sources and older literature, we do not deal with them in particular in this paper (Lexicon, 2010).

half of the 15th century Serbia accounted for the production of one quarter or one fifth of silver in Europe. In addition, it also produced iron, lead and copper. According to some estimates, more than 30 tons of silver and gold were produced annually in the territory of Serbia and Bosnia, while in the first half of the 15th century this production was estimated at minimum 10 tons (Ćirković et al., 2002; Fostikov, 2019).

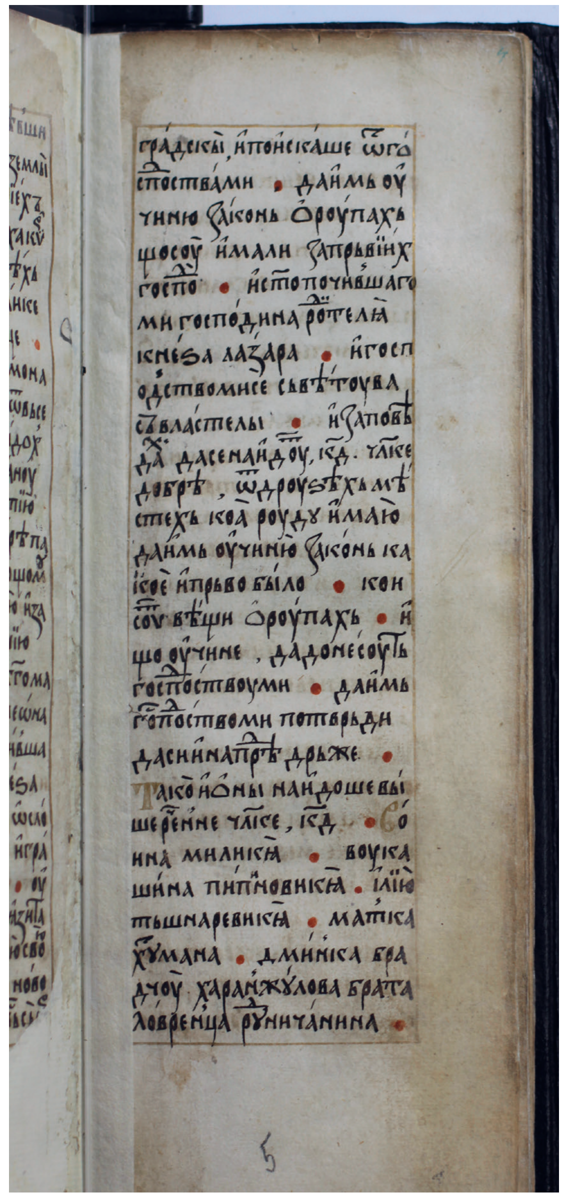
After the fall of the Serbian Despotate under the Ottoman rule, the mines first stagnated, and some of them were even destroyed, while the organization of their operation was also changed under the new rule. Nevertheless, after several decades, mining was once again revived vigorously, and from the original Turkish texts, the operation of the important mines can be followed (Mišić, 2014, p. 109; Amedoski, Petrović, 2018, pp. 1126–1127).

Organization of mining, legislation and urbanization

The organization of mine operations was regulated by laws and customs, which gradually turned into quite detailed mining codes that regulated not only the work of the miners, mining facilities or mining artisans who participated in mining operations, but also the method of cutting forests necessary for the process of melting and construction of underground installations. Furthermore, the same laws, codes or accompanying statutes of mining towns also regulated the operation of the market places for the sake of protecting miners, who had the right of first refusal regarding certain necessities. A large amount of data about mining jobs is provided by Despot Stefan's Mining Code and, according to the parallels and comparative bases from the preserved codes from individual mining towns, such as Kutná Hora *Ius regale montanorum* or the subsequent work by Agricola, which also contains drawings of the operations in mines and surrounding complexes, it is not difficult to imagine either the miners' hard work or the mining system, as well as ore processing and refinement, but also the work supervision system (Agricola, 1556; Radojčić, 1962; Marković, 1985; Bílek, 2000; Ćirković, 2005; Katić, 2024). Speaking of mining, organization of work and legislation, it must be pointed out that mining is exactly the proper example of early proto-industrialization, the foundations of which are found in the operation of mechanical machines, small complexes/metalworking factories, the application of corporate law, social protection, shift work, high division of labour, and export production (Fostikov, 2022). Just as today, mining was also a risky occupation in the past. Apart from the collapse of subterranean structures, the problem is also posed by fires caused by gas accumulation, while fighting mine shaft floods was also common at the time (Ćirković et al., 2002, pp. 60–61).

All those laws, as well as subsequent codes, were essentially based on the so-called Old Saxon *pravice*, or mining law, also known as *ius Theutonicum*, which referred not only to mining, but also to the mining towns (*montans*) whose development was affected by it (Szende, 2019). Therefore, the mining towns were specially organized, like islands in the feudal sea, while the accelerated urbanization process based on such rights led to an increased influx of population which gravitated towards these towns in the mining regions. Moreover, when the

Illustrated transcript of Despot Stefan Lazarević's Code on Mines from the 16th century, Collegium of Mining, Archives of the SASA 465, sheet 2v. The Code itself dates back to 1412.
Photo: Archives of the SASA



Illustrated transcript of Despot Stefan Lazarević's Code on Mines from the 16th century, Archives of the SASA 465, sheet 5r. The Code itself dates back to 1412.
Photo: Archives of the SASA

mines were opened and expanded, there had to be at least some infrastructure of workforce, in which the primary place was held by miners and mine artisans (Katić, 2009; Petrović, 2011; Fostikov, 2021).

An excellent example of mining legislation, which covered both work in mines and the organization of mining settlements and the miners' rights in everyday life, is offered by the local code known as Despot Stefan's Code, whose Cyrillic version is accompanied by an excerpt from the Statute of Novo Brdo, to which it actually refers. It is a domestic version created on the basis of domestic custom norms of the miners, and the reception of Old Saxon law, two centuries after the arrival of the first Old Saxon miners, when the expert council of 24 good men was established for the purpose of codification and/or selection and establishment of appropriate norms. During that period and after its acceptance, Old Saxon law developed in the new language environment and in different, specific social and territorial conditions so that, naturally, a necessity arose for the re-codification of the older number of laws and custom norms. Although the Cyrillic version bears 1412 as the year of publication, according to the critical analysis it may be concluded not only that the Code was prepared much earlier, but also that it is a later version of codification (Radojčić, 1962, p. 31; Marković, 1985, p. 35; Ćirković, 2005, pp. 72–73; Ivanović, 2015, pp. 159–187; Katančević, 2020, p. 277; Ivanović, 2023, pp. 580-585; Fostikov and Rokai, in the process of preparation).

The rise of mining was also accompanied by the rise of other branches of economy, particularly crafts and organized trade, as well as the process of accelerated urbanization, while of indisputable significance is the appearance of money as a medium of exchange is. First of all, there was a rise in those crafts that were necessary for the operation of the mines and the life of the miners, and then, with the rise of towns and urbanization, also those necessary for everyday life of the inhabitants flowing into the mining regions. At the same time, the rise of money industry also led to the opening of money mints, while increasing emissions led to the transition to monetary economy. Based on the first money emissions, it is believed that the first money was minted in Brskovo after 1253 (Ivanišević, 2001; Gogić, 2010, pp. 208-209; Fostikov, 2019; Fostikov, 2021). In addition, one of the consequences accompanying the development of mining towns is the change in the religious structure of the population, now including Catholic miners, but also the seaside merchants, primarily those from Kotor, and later from Dubrovnik, who established their trading colonies in the mining towns. According to written sources, the first Catholic parish is mentioned in Trepča as early as 1303 (Ćirković, 199; Gogić, 2016).

Mining and the environment in the Middle Ages

Speaking of mining, which consists of two segments – the first referring to extraction, and the second belonging to the sphere of primary and secondary processing – it can be clearly seen that mines are a combination of subterranean structures and surface processing facilities. These facilities are small complexes, often in a series, in line with the need for continuous water and fuel supply. That is why in the past, depending on the geographic location, they were situated next to the mines and sometimes a little farther from them. The fact that the only fuel at that time was wood and then charcoal, as well as that wood was necessary for building both subterranean and surface structures, and also for building facilities for everyday life, clearly indicates that during the Middle Ages huge deforestation took place which led to some regions becoming bare even at that time. The Old Saxon *pravice* implied that forests could first be cut without any control, as well as that the cleared space could be used in line with the miners' needs, while the restriction of that right was introduced as late as the mid-14th century, within Emperor Dušan's Code, which stipulates that the place intended for wood cutting must remain unpopulated in order to create conditions for the growth of new forests (Mrgić, 2010, p. 95; Fostikov, 2019).

However, a much larger problem than wood cutting, undermining the natural eco-system and air processing, was air and soil pollution, partly due to extraction and even more due to ore processing and refinement and the production of huge quantities of charcoal necessary for the operation of foundries. The poor air quality was complained about by the inhabitants of Srebrenica who, because of suffocation, asked for the displacement of the foundries from the centre of their settlement, while the water in Srebrenica was so polluted that it caused widespread goitre. Water pollution in Majdanska reka led to the lack of water in that region, while the people from Dubrovnik believed that Rudnik itself was an unhealthy place that should be avoided. Agricola in his own time was already aware of numerous problems with the eco-system and health and, in that respect, he listed a series of data in his book on metallurgy, drawing attention both to diseases affecting miners and to the harms to the environment and general health. Recent research point to a particular problem of soil pollution caused by the disposal of ore waste, whose decomposition leads to increased concentration of toxic elements (arsenic, lead, nickel and chromium). The explorations conducted in Rudnik and Srebrenica have shown that such effect on the environment lasts for several centuries. In the end, speaking of mining, including medieval mining, with the aid of new technologies it has been established that air pollution has always followed the line of mining development. When mining was on the rise, pollution also increased, while in the periods of the declining mining activity, air was purified (Brännvall et al., 1999; Ćirković et al., 2002, p. 58; Vranić, 2021).

Conclusion

From all the above-mentioned, as well as according to the opus of papers dedicated to mining in medieval Serbia and beyond, we can conclude that this topic is one of those that in themselves deserve, but also require being studied in further research of written sources, archaeological explorations and the broader and as interdisciplinary research as possible, on comprehensive comparative foundations. Only in this manner can this topic be more deeply perceived and studied. Therefore, in the future it is necessary to gather an interdisciplinary national and international team which will dedicate attention to this issue in order to synthetize certain phenomena, processes and factors.

Brskovo, area of medieval mining activity, archaeological research in 2023.
Photo: Mirko Vranić

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About lithium and lithium in Serbia

Abstract: This paper summarizes basic information about lithium, its physical and chemical characteristics and its occurrence in different minerals, especially in jadarite. A review of different types of application of lithium and their compounds in different industries, especially in medicine, is presented here. Also, the review of literature data on lithium occurrence in water and various food and its influence on humans is described. The role of lithium in warfare is also mentioned. Detailed data on different types of lithium batteries, including the new type of lithium batteries with solid electrolyte is given. Data on lithium production and lithium demand, including the increase of lithium demand in the near future is summarized in this article. In the part related to the Serbian Jadar project, some basic data on this project is given; that includes the technological procedure of lithium production, solid and liquid waste and landfill for waste deposition, especially in regard to the environmental protection. The part of beginning with the subtitle “Shouting and shame about lithium in Serbia” contains critical review on numerous nonsensical claims, misinformation and lies about lithium and Jadar project, especially about sulphuric acid and lithium toxicity that were spread across Serbia in the past four years, becoming an object of intimidation of Serbian citizens. Aiming to show how nonsensical and false these claims are, the data from valid and credible verifiable sources were cited. The final part of the text contains proposals about things that should be done in relation to the Jadar project.

Keywords: lithium, occurrence and production, application, Jadar project

About lithium

Lithium is the third element in the periodic system of elements, and belongs to the group of alkali metals. Its chemical symbol is *Li*. Its name is derived from the Greek word for stone (*lithos*). Even though it is one of the three elements produced in the Big Bang, there is very little of it in the universe, and is not found in a free state in nature. It is very scarce in the universe (0.0007% in the Earth’s crust), even

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though it is one of the three elements, along with hydrogen and helium, which were created at the very beginning of the universe. According to this theory of origin, the universe should contain three times as much lithium as is calculated from the oldest stars (in cosmology this is the problem of "lithium deficiency") (Fields, 2011). It was discovered in 1790 in the mineral petalite ($LiAlSi_4O_{10}$), based on the carmine red colour it exhibited in a flame (Figure 1). For this reason, lithium is also used in the manufacture of pyrotechnics.

Figure 1: Carmine red colour of lithium in a flame.
Source: Wikipedia

Lithium has an atomic number of 3 and an atomic mass of 6.941. It is a silvery-white metal, very soft. It has a hardness of 0.6 on the Mohs scale, which means it is softer than talc, which has a hardness of 1. It occurs in the form of 10 isotopes, of which 2 are stable in nature, the most abundant being Li-7 (92.5% natural abundance) and Li-6 (7.5% natural abundance). It has the lowest density of all metals, 0.534 g/cm^3, which, together with a redox potential of -3.04 V, makes it very suitable for use in lithium-ion batteries. Lithium has the highest melting point (182 °C) and boiling point (1,342 oC) of all alkali metals. It also has the highest specific heat capacity, which is 3,570 J/kg K. (Specific heat capacity is the amount of heat required to raise the temperature of 1 kilogram of a substance by 1 °C and for water it is 4,185.5 J/kg K). At very high pressure (400,000 atmospheres) lithium becomes superconductive (Rumble, 2017). Like all alkali metals, lithium is reactive and flammable and releases hydrogen with water, which is why it is not found in nature in its free state. Pure lithium must be stored in a vacuum, in an inert atmosphere, or under an organic liquid (kerosene, mineral oil).

Occurrence

So far, 124 minerals are known to contain lithium (Edward, 2020), and it is most commonly found in the following minerals: *amblygonite, cookeite, elbaite, eucryptite, faizievite, Finniss Lithium Project, fluor-liddicoatite, hectorite, jadarite, lepidolite, lithiophilite, lithiophosphate, nambulite, neptunite, petalite, pezzottaite, saliotite, spodumene, sugilite, tourmaline, triphylite, zabuyelite, zektzerite, zinnwaldite.*

In Serbia, in the valley of the Jadar River, about ten kilometres southwest of Mount Cer, the mineral jadarite (Stanley et al., 2007), which contains lithium and boron, was discovered in 2004. It is a monoclinic silicate mineral with the chemical formula $LiNaSiB_3O_7(OH)$ or $Na_2OLi_2O(SiO_2)_2(B_2O_3)_3H_2O$. The International Mineralogical

Association recognised the new mineral under this name (2006–36) (Jadarite Mineral Data).

Jadarite, named after its location in the Jadar River valley (about ten kilometres southwest of Mount Cer), is a monoclinic silicate mineral. Its chemical composition is sodium lithium boron silicate hydroxide ($LiNaSiB_3O_7(OH)$ or $Na_2OLi_2O(SiO_2)_2(B_2O_3)_3H_2O$). Based on the chemical formula, the authors (Stanley et al, 2007) calculated the percentage content of individual components: Li_2O 7.3%, Na_2O 15.0%, SiO_2 26.4%, B_2O_3 47.2%, H_2O 4.3%, a total of 100.2% by weight. Webmineral (Jadarite Mineral Data) lists the following composition of jadarite: Li_2O 7.28% (Li 3.38%), Na_2O 14.96% (Na 11.1%), SiO_2 26.30% (Si 12.29%), B_2O_3 47.12% (B 14.63%), H_2O 4.31% (H 0.48%). Jadarite occurs in the form of small crystals (5 -10 mm). When it comes to the average composition of lithium and boron in jadarite, the average content of Li_2O is 1.8% and B_2O_3 is 13.1%.

Seawater contains approximately 0.17 mg/l, rivers generally only 3 mg/l, while mineral waters can contain 0.05 – 1 mg/l (Lenntech). Larger amounts of lithium are found in the water of Carlsbad, Marienbad and Vichy (Kavanagh et al., 2018). Lithium is found in solutions only in the form of the Li^+ ion. Groundwater can contain significantly higher amounts of lithium, even more than 500 mg/L (Kavanagh et al., 2017), but the lithium content in these waters is generally between 0.5 and 19 mg/L (Figueroa et al., 2012). In northern Chile, however, the lithium content in drinking water, but also in food, is 100 to 10,000 times higher than in rivers in North America (Figueroa et al., 2012).

Soil contains an average of about 20 mg/kg of lithium (Kavanagh et al., 2018).

Application of lithium

Lithium does not react with oxygen. In humid air, lithium reactions with nitrogen and other gases in the air are slow, forming lithium nitride (Li_3N), lithium hydroxide (LiOH), and lithium carbonate (Li_2CO_3). It reacts with halogen elements to form the corresponding halides (lithium fluoride, lithium chloride, lithium bromide, and lithium iodide). Lithium hydrides (LiBH, LiAlH) are reagents widely used in organic synthesis. Lithium reacts with acids to produce lithium sulphate, lithium nitrate, and lithium chloride.

Metallic lithium is produced by electrolysis from molten salts of lithium chloride and potassium chloride.

Some lithium compounds, such as lithium chloride and lithium bromide, are highly hygroscopic (absorb moisture), and are used in industrial gases drying. Lithium hydroxide and lithium peroxide (Li_2O_2) are used to remove carbon dioxide and purify the air in confined spaces, such as spacecraft and submarines. Lithium hydroxide was also used in the Apollo space missions, as it absorbs carbon dioxide and forms lithium carbonate. Lithium peroxide also reacts with carbon dioxide in the presence of moisture, forming lithium carbonate, while releasing oxygen. An "oxygen candle", or lithium perchlorate, releases oxygen and is used in submarines.

Lithium and its ores have long been used in glass production and ceramic industries, and until recently, they were the most widely and frequently used. Lithium ores (spodumene, amblygonite, lepidolite, and petalite) are used to reduce the viscosity and lower the production temperature of glass and ceramics, thereby reducing production costs. Lithium has a low coefficient of thermal expansion, so when added to molten glass it reduces the thermal expansion and fluidity of the glass. Adding 0.17% lithium oxide (Li_2O) to glass reduces the melting temperature by 25 °C, thereby saving 5-10% energy. The addition of lithium creates pyroceramic products, i.e. products resistant to high temperatures, which are used to make furnaces for insulating materials with extended service life, resistant to temperature shocks, with enhanced mechanical properties and increased surface tension. Lithium fluoride crystals are used to make special optical parts, which are used for ultraviolet (UV) and infrared (IR) optics, which is especially useful in the construction of telescopes with enhanced properties.

Lithium is widely used in steel industry, especially in the production of aluminium, where lithium carbonate significantly reduces energy consumption (in 1996, about 40% of all lithium in the United States was spent on aluminium production). In addition, it is used to make many alloys, since it is the lightest metal, and light alloys with improved strength are obtained (alloys with aluminium and magnesium for the production of light but strong parts for aircraft).

Lithium is also used for the production of special glasses (pyrex) resistant to temperature, for the production of touch screens, in the pharmaceutical industry, the production of fibreglass, special glasses for glass-ceramic stoves and for induction furnaces.

Numerous organic lithium compounds are used in the chemical industry, as catalysts, in polymerization, as reducing agents, and for the production of special lubricants (lithium stearate) resistant to high temperatures.

Application in medicine

Lithium is also widely used in medicine. It has beneficial neurological effects, and has been used for a long time, since the time of ancient Rome, to treat neurological diseases. Soranus of Ephesus, a Roman physician, discovered that patients who drank alkaline water (with an increased lithium content) had better health (Thomson, 2007). Even without knowledge of lithium, Soranus discovered an improvement in health for bone pain, as well as for the treatment of manic symptoms.

Lithium has been used as early as 1845 to treat gout because it was established that a solution of lithium salts dissolved uric acid crystals in the urine, which formed gout (Schrauser, 2002, Kaill, 1999). It was assumed that an "imbalance of urate" (uric acid salts) lead to many diseases. It is also known that uric acid is a psychoactive substance, so it was assumed that lithium treatment, which would reduce uric acid levels, would help in the treatment of patients with acute mania (Oruch et al., 2014). Thus, in the 1920s, lithium became known as a miracle nerve-protecting agent, and for a time it was added to some soft drinks, such as "*Lemon-Lime Soda*", the predecessor of the *7-up* soda (where lithium was the original "*up*" ingredient), and "*Lithia Water*" (Davis, 1987). In some parts of the world, lithium chloride was used as a substitute for table salt (sodium chloride), especially for people who had a diet low in sodium. The wide application of lithium in the diet or in soft drinks could lead to harmful effects due to excessive amounts of lithium, so the use of lithium in soft drinks was prohibited. Since 1880, lithium has been used to treat patients with acute mania, as well as those prone to suicide. The increased use of lithium (lithium carbonate) for the treatment of mental illness began in 1940, when Australian psychiatrist Dr. John Cade, while treating such patients, found that lithium carbonate had a calming effect on patients. Lithium carbonate, as well as lithium acetate, lithium aspartate, lithium citrate, lithium borate, lithium orotate, and lithium sulphate, were used to treat bipolar disorder (manic depression), which resulted in a decrease in suicides (Kaill, 1999). Lithium salts (most commonly lithium carbonate) are also used to treat schizophrenia and addiction. Lithium interacts with neurotransmitters (stimulant transmitters) and receptors in the human brain, increasing serotonin levels and decreasing norepinephrine (a hormone and neurotransmitter) production in the brain. It is a very complex process that has not been fully studied, although there are already nine theories about it and further research is forthcoming.

Figure 2. Lithium is also used in medicine to treat neurological diseases.
Photo: Shutterstock

Therapeutic doses of lithium prescribed for the treatment of the aforementioned mental disorders and diseases range from 600 to 2,400 milligrams/day (Mayo Clinic, Minddisorder).

Lithium efficacy in the management of acute mania was approved by the *US Food and Drug Administration (FDA)* in 1970. Other conditions that have been treated with lithium include headache, high blood pressure, diabetes, epilepsy, arthritis, dementia (Timmer et al., 1999, Kessing et al., 2010), and even tooth decay.

No cases of the stated acute or chronic poisoning from natural sources of lithium have been reported in the literature. In humans, ingestion of more than 5 g of lithium chloride can result in fatal toxicity (Shahzad et al., 2017, Aral et al., 2008). Another estimate for the lethal dose is up to 90 mg/kg body weight of lithium, which means about 6,300 mg (6.3 grams) of lithium for an average weight of 70 kg, according to Koen van Deun et al (Van Deun et al., 2021).

Lithium in water and food and its impact

Lithium in small concentrations is useful in human nutrition, and no data in literature indicates any physiological symptoms of a diet that lacks in lithium. A study done in Texas (US) in 1990 records beneficial effects of lithium. Over the span of more than ten years, a reduction in the number of suicides had been recorded, as well as home homicides and rapes in the area where lithium concentration in the drinking water was in the range of 0.07 – 0.160 mg/l (Bluml et al., 2013). This study also confirmed beneficial effects of lithium on the reduction of violence and the number of suicides, even at concentrations found in drinking water (Schrauzer et al., 1990, Giotakos et al., 2013, Liaugaudaite et al., 2017). Similar studies have been done in Japan, Austria, in the East of England, and they have shown that the number of suicides declined in places where the concentration of lithium in drinking water had been increased.

Due to its exceptional effects as a protector of the nervous system, lithium is also used in medicine in pretty high dose (600 to 2,400 milligrams per day), especially in psychiatry, for treatment of various forms of manic, schizophrenic, and bipolar disorders. This is why comprehensive studies looked into possible effects of significantly smaller doses of lithium on people, as seen in drinking water or in foodstuffs (Szklarska et al., 2019). The confirmed results regarding the reduction in the number of suicides, domestic murders, addiction-related diseases, and crime have prompted many scientists to seriously investigate the effects of small concentrations of lithium on humans, such as those found in drinking water or food products. Such studies have also emerged from the need to determine whether the global suicide rate, which is around 800,000 per year, can be reduced (WHO, 2017). A large number of suicides is most common in highly developed countries, as confirmed by the example of Europe (Kovess-Masfety et al., 2011). Suicides are most often committed due to a diagnosed illness or due to bipolar disorder (Phillips, 2010). One of the objectives of these studies is to determine the smallest dose of lithium, introduced through water or food, which has a positive effect on reducing crime and the number of suicides and domestic murders (Schrauzer et al., 1990). Numerous papers have highlighted the justification for such research (Schrauzer et al., 1990, Young, 2009, Ohgami et al., 2009, Kapusta et al., 2011, Sugawara et al., 2013, Giotakos et al., 2013, Liaugaudaite et al., 2017).

Daily lithium intake differs in various parts of the world and depends on the availability of lithium in the environment and foodstuffs, and its concentration ranges from several micrograms to several thousand micrograms a day. Schrauzer proposes that the daily lithium intake should be around 1,000 μg (1 mg)/day for adults weighing 70 kg (14.3 μg/kg) (Schrauzer, 2002). Due to uneven distribution of lithium in Earth's surface, its concentrations differ in various parts of the world, but it is known that the ones in Europe are among the lowest. And so, data states that the intake of lithium in Poland is only 10.7 μg/day, and 8.6 μg/day in Belgium.

The main sources of lithium in the diet are cereals, potatoes, tomatoes, cabbage, some mineral waters, and certain spices, although the intake through spices is negligible. The average lithium content is 4.4 μg/g of dry matter in cereals, 3.1 μg/g of dry matter in fish, 0.19 μg/g of dry matter in mushrooms, 2.3 μg/g of dry matter in vegetables, 0.5 μg/g of dry matter in dairy products, 8.8 μg/g of dry matter in nuts, and only 0.012 μg/g of dry matter in meat. Bottled water in Europe contains an average of about 0.94 μg/l, while tap water contains an average of 0.54 – 0.64 μg/l. From these data, it is clear that it is almost impossible to reach the recommended daily intake of lithium, which is about 1,000 μg, through food alone.

Numerous studies have shown the importance of lithium's effects, which is found in water, on the reduction of suicides, even though such doses are significantly smaller than the ones used in treatment of bipolar disorders, which are the most frequent cause of suicide (Schrauzer et al., 1990). These results were obtained from studies conducted in the US, Japan, Austria, Greece, Italy, Lithuania, and Denmark. It is assumed that a very small intake of lithium causes worsened mood, impulsivity, and anxiety (Sher, 2015). Such results partially confirm the assumption about the increase in violence and the number of suicides and domestic homicides in people living in areas with small concentrations of lithium in drinking water (0 - 12 µg/l). For this reason, it has been suggested that lithium be introduced through dietary supplements, similar to how iodine is added to table salt.

Lithium in warfare

Lithium is used in the production of so-called hydrogen (thermonuclear) bombs. The lithium isotope, *Li-6*, and the hydrogen isotope, *H-2* (deuterium), absorb neutrons and decay into helium and tritium (a hydrogen isotope), releasing enough energy to initiate a nuclear fusion (combination) reaction, which results in the formation of two helium atoms. These bombs release an enormous amount of energy and have a yield of millions of tons of TNT (trinitrotoluene, a classic explosive).

Lithium hydride and lithium aluminium hydride are used as high-energy additives in rocket fuel. The production of rocket weaponry also requires materials that are resistant to high temperatures and have low thermal expansion, so lithium salts are used in the creation of such composite materials (Kunasz, 2006). In addition, lithium batteries are used in many electronic devices essential for modern warfare.

Lithium batteries

Lithium batteries can be primary (non-rechargeable), and these are typically button-shaped or cylindrical batteries used in calculators, wristwatches, and early digital cameras. Compared to traditional alkaline batteries, lithium batteries have a higher energy density, are lighter, and have a longer lifespan.

Figure 3. Primary lithium batteries.
Photo: Shutterstock

Another type of lithium battery is the secondary (rechargeable) lithium-ion battery, which is used in mobile phones, laptops, numerous small electronic devices, various power tools, electric cars, and other vehicles, and more recently, for energy storage.

These batteries also have a higher energy density, lower mass (weight), and a longer lifespan. To produce 1 kWh (kilowatt-hour), 0.16 – 0.18 kg of lithium carbonate is required. Energy density, expressed in Wh/kg, is the amount of energy that can be stored in a unit of mass. Power density, expressed in W/kg, is the amount of power that can be generated from a unit of mass. A lithium-ion battery for newer mobile phones contains about 3 grams, a battery for a laptop computer contains 10 – 30 grams, a battery for power tools contains about 40 – 60 grams, and a battery for cars and trucks contains 40 – 100 kilograms of lithium carbonate.

Figure 4. Secondary lithium batteries.
Photo: Shutterstock

A lithium battery consists of several individual cells connected together. Each cell is made up of a positive electrode (cathode), a negative electrode (anode), a separator that separates the cathode from the anode, and an electrolyte (which can be liquid, gel-like, or solid). Since lithium is extremely reactive in its elemental form, lithium-ion batteries do not contain elemental lithium, but rather an oxide, such as lithium cobalt oxide. These batteries are rechargeable, meaning that the cycles (discharges and recharges) can be repeated hundreds (or thousands) of times. Lithium-ion batteries have the highest charge density compared to any other type of battery.

There are six types of lithium-ion batteries.

1. *Lithium-cobalt-oxide, $LiCoO_2$* ***(LCO)*** battery, where lithium oxide is the cathode and graphite is the anode. Its operating voltage is 3.6 V, specific energy is 150-200 Wh/kg, energy density is 400 Wh/l, and the number of charge/discharge cycles is 500-1,000. They are used in newer mobile phones.
2. *Lithium-manganese-oxide, $LiMn_2O_4$,* ***(LMO)*** battery, has a cathode made of lithium manganese oxide and an anode made of graphite. It has an operating voltage of 3.7 V, specific energy of 100-150 Wh/kg, and energy density of 350 Wh/l. The number of charge/discharge cycles is 300-700, and it is used in electric bicycles, garden machinery, medical equipment, and in screwdrivers and drills.
3. *Lithium-iron-phosphate, $LiFePO_4$* ***(LFP)*** battery
   Where high specific energy is not required, but high safety, long cycle life, and large battery capacity are needed, lithium iron phosphate batteries are used. They are also used in the automotive industry (electric vehicles), for industrial machines in automation, robotics, for various types of vehicles, airport vehicles, and more. They have an operating voltage of 3.2 V, specific energy of 170 Wh/kg, and energy density of 350 Wh/l. Their number of charge/discharge cycles exceeds 4,000, which has led to the widespread use of these batteries in many electric vehicles.

4. *Nickel-manganese-cobalt, LiNixMnyCozO$_2$* ***(NMC)*** battery
   This battery uses a mixed oxide of nickel, manganese, and cobalt. It has a high specific energy (220 – 240 Wh/kg). Such batteries are most commonly used in the electric vehicle industry because they can deliver a large amount of energy stored in a small mass and volume. They have an operating voltage of 3.6 V, specific energy of 150-220 Wh/kg, and energy density of 500 Wh/l. Their number of charge/discharge cycles ranges from 1,000 to 2,000.
5. *Nickel-cobalt-aluminium, $LiNiCoAlO_2$,* ***(NCA)*** battery
   In the automotive industry, these batteries are most commonly used for the production of electric vehicles. They have an operating voltage of 3.6 V, specific energy of 250 Wh/kg, and energy density of 550 Wh/l. Their number of charge/discharge cycles exceeds 1,000.
6. *Lithium titanate, $Li_4Ti_5O_{12}$* ***(LTO)*** battery
   The characteristic of this type of battery is its exceptionally high number of cycles (charge/discharge), ranging from 15,000 to 20,000. These batteries have a lower energy density. Their operating voltage is 2.4 V, specific energy is 70 Wh/kg, and energy density is 177 Wh/l. They have a number of charge/discharge cycles greater than 15,000 – 20,000. They are used in the automotive industry.

Lithium-ion batteries with solid electrolyte

The latest type of lithium-ion batteries is the one with a solid electrolyte. These batteries represent huge progress compared to lithium -ion batteries with liquid electrolytes. They have larger capacity, longer charge/discharge cycle, and quicker charging times. They are completely safe as they cannot combust. Solid-state lithium-ion batteries do not generate flammable gases, which makes them the safest lithium-ion batteries. Solid-state electrolytes are non-toxic and have no impact on the environment, do not evaporate, are thermally stable, have good mechanic properties, good ionic conductivity, allow the diffusion of lithium ions and will have a significantly shorter charging time. It is stated that solid-state electrolytes with sulphides (lithium, sulphur, chlorine, etc.), oxides (lithium, titanium, zirconium, aluminium, tantalum, lanthanum), and phosphates (lithium, phosphorus, aluminium, titanium, germanium) have been successfully applied so far. The Japanese car manufacturer, Toyota, has announced the production of such batteries by 2028. With these new batteries, cars will be able to travel up to 1,200 kilometres, and the charging time will be reduced to ten minutes.

Lithium production and demand

Due to the increasing use of lithium-ion batteries, not only for the production of electric cars but also for the production of many electrical and electronic devices, the demand for lithium is constantly rising. A significant increase in demand for lithium is also predicted in the next ten to twenty years. This increase in demand has been influenced by the decisions of many governments to ban the use of internal combustion engine cars within the next decade.

For example, the ban on the production of internal combustion engine cars will apply in Norway until 2025, in the EU and the UK until 2035. In the US, half of the cars sold by 2030 are expected to have „zero emissions." It is predicted that in China, by 2025, half of the cars will be powered by „new energy," while in India, by 2030, about 30% of the cars sold will be electric. In Japan, a ban on the sale of internal combustion engine cars is planned for 2030.

Given these already made decisions, many governments are already taking measures to ensure sufficient quantities of lithium to meet the growing demand. The European automotive industry currently imports 100% of the raw materials for production (lithium, cobalt), mostly from China, so the EU has adopted regulations aiming to reduce this dependency as soon as possible. This list includes thirty-four „critical raw materials." In addition to lithium, there are rare metals that are essential for the production of lithium-ion batteries, as well as for the production of semiconductors and special alloys. These raw materials are necessary for the EU to progress, not only in the production of electric cars but also in the production of semiconductors, computer technology, and artificial intelligence.

The largest lithium reserves (about 60% of the world's reserves) are located in South America, in Argentina, Bolivia, and Chile (in the so-called *ABC triangle* – **A**rgentina, **B**olivia, **C**hile). The top ten countries with the largest lithium reserves are Bolivia (21 million tons), Argentina (19 million), Chile (9.8 million), Australia (7.3 million), China (5.1 million), DR Congo (3 million), Canada (2.9 million), Germany (2.7 million), Mexico (1.7 million), Czech Republic (1.3 million), and Serbia (1.2 million). The largest lithium producers, according to 2021 data, are Australia (around 55,000 tons of lithium annually), Chile (26,000 tons), China (14,000 tons), and Argentina (6,200 tons).

According to the *EV Battery Market* forecast for 2033 (EV Battery Market), the global battery market will be worth around 508.8 billion dollars, with lithium-ion batteries holding the largest share of this value. This forecast is also based on the production of new types of batteries with improved characteristics and extended lifespan. The forecast also applies to Europe, where there has been an improvement in lithium-ion battery technology, which now has higher energy density, shorter charging times, longer operational life, and improved safety during use.

Here is the forecast for the increase in lithium demand over the next twenty years.

In China, which is the world's largest producer of lithium-ion batteries (with around 75% of global production), there are also the largest number of large (gigafactories) battery plants. In Europe, around 11% is produced, in the US around 7%, and in all other countries, around 7% of the total global battery production. It is predicted that by 2033, the share of European manufacturers will increase to 22%, at the expense of Chinese manufacturers whose share is expected to fall to 55%, the US to 18%, while all other countries will produce only 5% of total global production. This forecast is supported by data on the construction of new gigafactories for lithium-ion batteries: in Germany (14), Norway (4), Sweden (3), Hungary (5), France (5), Spain (8), Italy (4), and one each in Poland, Russia, the Czech Republic, and Serbia (France24). As a result, the EU has signed memoranda of understanding with Argentina and Serbia (in 2023) to ensure sufficient lithium supplies for the factories whose construction is planned.

To accelerate this process, the EU plans to allocate three billion euros in incentives for lithium production, while the US plans an investment of around sixty billion dollars for the same purposes. This is particularly emphasized in countries that host major car and truck manufacturers (*AB Volvo, Mercedes Benz Group AG* and *Scania AB*).

Jadar Project

As already stated, jadarite was unearthed in 2004, in the Valley of the Jadar River, 10 or so kilometres southwest of the Cer Mountain in Serbia (Stanley et

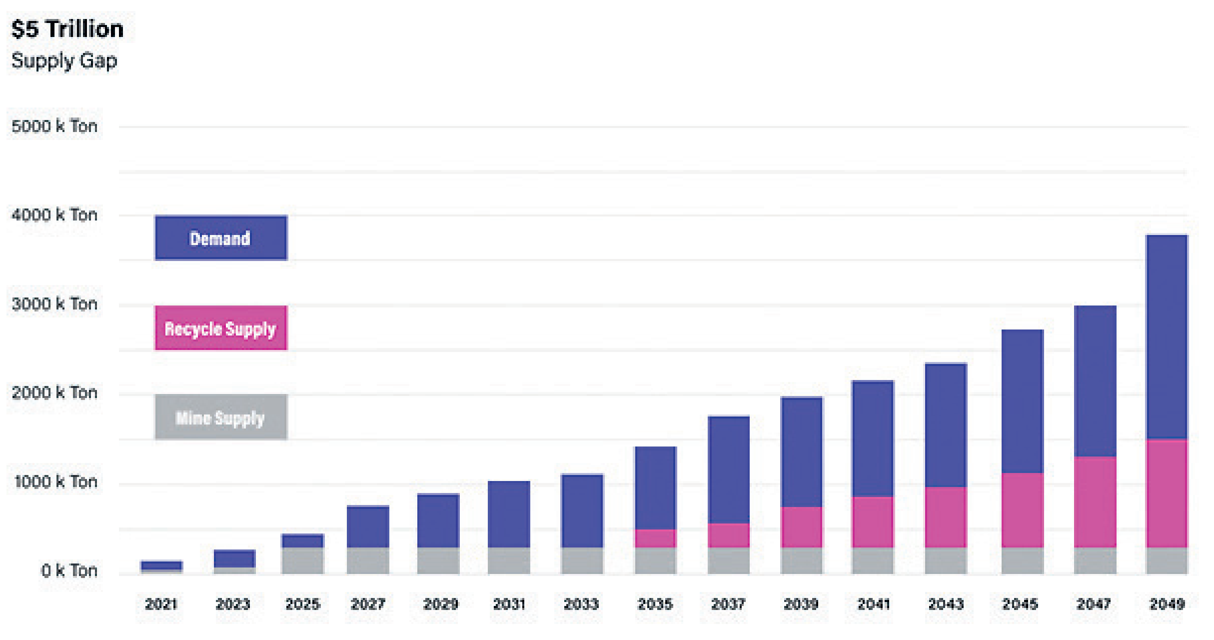

Figure 5. Predicted lithium demand by 2049 (blue bars), lithium obtained from recycling (purple bars), and lithium production from mines (grey bars).
Source: Wall Street Star

al, 2007), a mineral that contains lithium and boron. Its chemical composition is sodium lithium boron silicate hydroxide ($LiNaSiB_{3O7}(OH)$ or $Na_2OLi_2O(-SiO_2)_2(B_2O_3)_3H_2O$), with an average lithium content of 1.8%, or 3.04% (as Li_2O, after enrichment), and a boron content of 13.1%.

In this paper, we will not address the mining aspect of this project, but only the technological process for the production of lithium carbonate and boric acid [Study 1], as well as the waste materials [Study 2] that are created during this process. Of course, this technological process is presented without delving into the details.

The technological process, after crushing and enriching the ore, includes dissolution with sulphuric acid, neutralization, selective crystallization, and the production of the final products: lithium carbonate, boric acid, and sodium sulphate as a by-product. In addition, this process also includes the treatment of wastewaters generated during production, as well as the processing of solid waste before it is sent to the landfill.

The project envisages the processing of approximately 1.9 million tons of jadarite ore annually, with the production of 58,000 tons of lithium carbonate, 286,000 tons of boric acid, and 259,000 tons of sodium sulphate as by-products, each per year. The jadarite ore concentrate is dissolved in sulphuric acid in closed vessels at a pH of 3, at 90°C, with the pH being maintained around 3 by adjusting the sulphuric acid and water dosage. This process results in a leachate rich in boron, lithium, and sulphates. By lowering the temperature, a saturated solution is obtained, from which boric acid crystallizes (two-stage crystallization). The precipitated boric acid is filtered, dried, and ground to a specified granulation. By adding slaked lime, magnesium and heavy metals are precipitated, and gypsum is formed. After the separation of boric acid and heavy metals, sodium bicarbonate is added to convert lithium sulphate into lithium bicarbonate, and by increasing the temperature, lithium bicarbonate is further converted into lithium carbonate. Through two-stage crystallization, lithium carbonate is obtained, which is then dried and ground to a specified granulation. In the remaining liquid, sulphuric acid is added to adjust the pH to 6-8, causing the formed carbonates to be converted into sulphates, while sodium sulphate crystallizes, is dried, and ground.

During the execution of the process, the exhaust gases are controlled: RM2.5 (particles the size of 2.5 mm, NO_2, CO, HCl, SO_4).

The treatment of wastewater from the production process involves five stages: ultrafiltration (removal of micron-sized particles), nanofiltration (removal of submicron particles, reverse osmosis 1, reverse osmosis 2 (removal of heavy metal ions), and ion exchange (removal of remaining ions). Demineralised water is obtained in that way, and in order for it to be discharged into the Jadar River, it is necessary to carry out mild mineralization (adding a certain amount of minerals to the level of concentrations present in the Jadar River).

Solid waste, obtained during the production process, is dried until it reaches a moisture content of 25%, and then it is being transferred to a solid waste landfill [Study 1]. The standard method for examining the dangers of solid waste is the so-called leaching test, and is prescribed by EU and US standards [Study 2]. This method is performed by pouring a certain amount of solid waste with a water solution (or an acid solution), stirring the sample continuously for a certain time, and then analysing the solution to determine the concentrations of washed heavy metals. Standards prescribe threshold concentrations of washed elements up to which the waste is considered harmless (Townsend et al., EPA). Among inorganic substances, arsenic, barium, cadmium, chromium, lead, mercury, selenium and silver are analysed. Tests of solid waste from the lithium and boron production process showed that the "washed" (leached) concentrations (antimony, arsenic, copper, mercury, cadmium, molybdenum, nickel, lead, chromium, zinc) from the solid waste were far below the limit (100-1,000 times below) acceptable by the mentioned standard. This means that the mentioned solid waste, generated during the production of lithium and boron, will not leach heavy metals and pollute the environment.

The technological procedure for obtaining lithium carbonate and boric acid from jadarite indicates that the usual and well-known technological processes are used: dissolution with acid, neutralization with a base, precipitation and crystallization, filtering, drying, grinding. There are no flammable or explosive substances, no high pressures, no high temperatures, and the cycle is completely closed. The entire technological process involves no unknown or new, untested processes.

Controversy over lithium in Serbia

Since 2004, when the mineral jadarite was discovered in the Jadar River valley (Stanley et al., 2007), until 2020, lithium was considered the safest and most useful element in the periodic table. The Jadar project was declared a strategic project for Serbia in 2008 and again in 2011. The 2011 Strategy of Mineral Resources Management of the Republic of Serbia until 2030 states, among other things: „The Jadar basin, with its quantity and content of lithium and boron in the ore, is one of the most significant potentials on a global scale." (Government of Serbia)

Since 2020, a negative campaign against the Jadar project has begun, spreading nonsense, inaccuracies, and lies. It all started with an interview given by D. Đorđević to a portal (Balkan Green Energy News) on December 9, 2000, which later became a political platform for certain parties and movements. Nothing said in that interview was true, and it was the first time the story about sulphuric acid at 250°C and hydrofluoric acid was introduced, even though the latter is not even used in this technological process. It is untrue that sulphuric acid at will be used 250°C, that the vapours of aggressive acids will evaporate into the atmosphere, that they will destroy the green cover, or that „waste mining water" will be discharged into the Jadar River, as no such waste exists. It is untrue that underground waters that could be used as drinking water will be endangered, and it is not true that the Drina River, then the Sava, and the cities along these rivers will be threatened. It is untrue that ores in our region contain extremely toxic elements, that flotation waste water will be discharged into the Jadar River (since there is no flotation in the process), or that Serbia will receive 4% of the mining royalties along with all the environmental catastrophes that will follow. It is untrue that all agriculture in the area surrounding the mine, along the Jadar River, and beyond, will be destroyed, and it is untrue that the environment will be polluted or that the population will suffer from the most severe, incurable diseases. It is untrue that toxic mining water came out of exploration wells. It is not true that waste water and thousands of tons of sulphuric acid will be discharged daily, or that due to the mine in western Serbia, cities like Loznica, Valjevo, Šabac, and Belgrade will run out of water. All lies, nonsense, and fabrications.

To make matters worse, all these lies were spread by people with academic degrees and titles. This explains why so many people believed these lies. Then, the negative campaign spread on social media, where everyone, literally everyone, could express their „opinion" about the Jadar project and lithium. People competed to present shocking information about the Jadar project and lithium, while some media outlets, alongside social networks, eagerly spread these lies. Here, anyone can say whatever they want about lithium, and this was led by some academics, actresses, doctors, gynaecologists, singers, athletes, directors, and filmmakers—basically, self-proclaimed experts on lithium. „Negative information, news, and rumours spread very quickly," much faster than positive ones. „Fake or negative news, rumours, and information spread rapidly and cause chaos and instability in the social order." „People become addicted to mobile phones," and as a result, they become disconnected from social reality (Sociology Group). Furthermore, social media leaves consequences, not just on mental, but also on physical health, and negatively impacts creativity. Constant use of social media makes people lazy and less active.

Given that over 15,000 negative articles about the Jadar project have been published in the last two years in our country, it is clear that it is impossible to disprove all the nonsense and lies told about this project in a single text. The author of this paper has repeatedly presented accurate and truthful data about the project. In the text „Lithium in Serbia: Then and Now" (Simonović, 2023), some of the nonsense and lies spoken by people with academic degrees and titles are mentioned. A worrying fact is that there are over 300,000 people in Serbia who claim to know everything about lithium („lithium experts"), but none of what they know is true. „At least 2,000 hectares of fertile land will be destroyed (it is actually 390 hectares), 22 villages will be displaced (52 households), 500 cubic meters of water will be used for one ton of lithium (it is actually 8-9 cubic meters), 10% of the world's lithium reserves are located here (it is actually 1.5%), sulphuric acid at 250°C (it is actually 90°C)."

The story about sulphuric acid at 250°C kept resurfacing, even though the author of that statement later contradicted herself. However, once the genie is out of the bottle, the professor from the Belgrade Faculty of Economics will be suffocated by sulphur gases and acid rain will fall on her head. Anyone can verify, if they look for the correct data about sulphuric acid, which is one of the most widely used raw materials in the chemical industry, how things really stand. The industrial development of a country is measured by its sulphuric acid consumption. Over 380 million tons of sulphuric acid are consumed worldwide annually, and in Serbia, over 600,000 tons per year. How false the story is about sulphur gases poisoning the residents of Jadar, Loznica, Šabac, Belgrade, and even the entire country, can be seen from the fact that sulphuric acid at 140°C evaporates five times less than water at 0°C (Marti et al., 1997). And it is known that water at 0°C practically does not evaporate, so there will be no sulphur gases and, consequently, no suffocating of Serbia's population. In the middle of Hamburg, a city with over two million inhabitants, there is a sulphuric acid plant, *Aurubis*, which produces two million tons of sulphuric acid annually. No one in Germany has thought of relocating this sulphuric acid plant that would suffocate the residents of Hamburg.

In another article (Simonović, 2024a), the author of this text pointed out the nonsense put forward by certain academics and demonstrated that they have no knowledge of the topic they are discussing and presenting falsehoods about. None of these loudest academics have ever dealt with lithium or environmental protection, but that has not stopped them from constantly speaking about lithium and environmental protection. In doing so, they have violated the Code of Conduct in scientific research, which „mandates that objectivity in interpretation and conclusions must be based on facts and data that can be proven and verified," and „impartiality and independence from interested parties, ideological or political groups" (Prosveta). None of the claims made by these anti-lithium advocates have been refuted with new data. The same article also mentions a political gathering on the Jadar project held at the Serbian Academy of Sciences and Arts (SANU) in 2021, which some academics claim was a scientific event. The tone of science at this political gathering was provided by various non-governmental organizations and citizen groups, as well as a letter sent to the then president of SANU by minor local NGOs and political parties.

Some academics, although it is not their area of interest or expertise, have put in tremendous effort to show that the Jadar project is catastrophic and the worst possible thing that could happen to Serbia, without providing any real evidence for their claims. It's all in the style of: "I know it is very dangerous, but I don't know what exactly is dangerous or why. But still, it's dangerous, more dangerous than you can imagine." They demonstrate such bias and present things that any reasonable person would be ashamed of. A good example of this are two articles by academic S. Vukosavić, a professor at the Faculty of Electrical Engineering (whose scientific fields he has listed include electromechanical energy conversion, digital control, and industrial robotics), published in Nin (Vukosavić, 2024a, Vukosavić, 2024b). He does not mention a single word about what is specifically dangerous about the lithium project. He claims "... the realization of the Jadar project would lead to massive devastation of the area, permanent changes to the landscape, land degradation, deforestation, contamination of surface and groundwater, displacement of the population, cessation of agricultural activities, and the establishment of a permanent health risk scenario for the population on a large scale." However, as true scientists do, academic Vukosavić does not provide any evidence for these claims of an impending catastrophe in Serbia, but he confidently declares that it will be "on a large scale." The unfounded nature of these catastrophic claims can be best seen by looking at the real data concerning the Jadar project. The term "massive devastation of the area" refers to about 300 hectares, which the Jadar project would occupy, representing only 1.02% of the total area of the Jadar region. If areas with settlements are excluded, this percentage is less than 0.5%. This data disproves Vukosavić's second claim about "permanent changes to the landscape." If he had taken the time to find accurate data on the land in this area, academic Vukosavić would have found that "the planned area is (partially) classified as a degraded environment with negative impacts on humans, plants, and animals" (Institute for Urban Planning, 2019). In 2014, a pond containing waste water and flotation sludge from antimony ore overflowed in this area, resulting in the release of "1.2 million tons of mining waste" and "over 110,000 cubic meters of tailings sludge" from the Stolice mine in Kostajnica, which entered the Kostajnik stream, a seasonal tributary of the Jadar River (Environmental Protection Agency, 2018). This incident contaminated 120.8 km^2, which makes up 41.1% of the total Jadar area (293.91 km^2). If areas with settlements are excluded, the percentage of permanently contaminated land is significantly higher, probably 60-70%. Considering the previously mentioned data on the type and degree of land and water contamination, all of academic Vukosavić's claims about some future agricultural production that would feed Serbia and part of Europe (as some street environmentalists have claimed) fall apart. Academic Vukosavić speaks of *"the establishment of a permanent health risk scenario for the population on a large scale."* However, he failed (again deliberately) to specify what those "permanent health risks for the population on a large scale" are. This is what happens when an academic gathers data for their claims from street protests and social media, while disregarding available real, reliable data.

The analysis by the Academy of Engineering Sciences of Serbia (AINS) is similar to the political gathering held at the SANU, with the only difference being that they added a few elements to make it seem different, even though it is fundamentally the same. They are even against investing significant funds in infrastructure (in line with the "everything must stop in Serbia" rhetoric), as if someone would take those roads, any potential railway, or other infrastructure out of Serbia, leaving it behind in the region. Here too, there is a strong push for the idea that "everything must stop in Serbia," even investments in infrastructure.

And the engineering academics are concerned "because the development of agriculture will be hindered." The author of this analysis seems to have forgotten what he wrote in the same statement, as he later writes the following: "It is indicative that, at a distance of 20 km down the Jadar River, arsenic concentrations were measured to be 8.9 times higher, and boron concentrations 17.1 times higher. In an area with increased concentrations of toxic substances in the soil, water, or air, profitable production of healthy food cannot be organized." So, it will not just be "hindered"; in fact, even before mining and lithium extraction begin, food production— of healthy or any kind of food — has already been rendered impossible. This AINS analysis contains the same nonsense and falsehoods as the conclusions from the aforementioned political meeting at the SANU, so it is obvious that the same hand wrote both of these conclusions. There is no sense in commenting on the nonsense about thousands of tons of boron, arsenic, nickel, cadmium, and lead. How could have the engineering academics overlooked the fact that someone planning to produce boron would release thousands of tons of boron, not to mention other expensive metals, into the tailings? Another catastrophic claim follows, stating that these thousands of tons of heavy metals and arsenic will "travel via the Sava River and through Šabac and Belgrade, creating a constant risk to the water supply security of much of Serbia." If this is coming from engineering academics, it is too much. Serbia is in trouble with such engineers and academics. How this AINS statement came about can be seen in Dr. S. Maksimović's reaction to the text by Academic S. Vukosavić (Maksimović, 2022). "Based on superficial statements, the text shows that the winds of new knowledge have led the academic into an unfamiliar territory of mineral raw materials exploitation and environmental protection. This explains why, as an expert in electrical control, he struggles in a vacuum without professional and scientific guidance. In an attempt to appear convincing, he references daily newspapers instead of authoritative mining and geological sources. He refers to the authority of a scientific gathering at the Serbian Academy of Sciences and Arts (SANU) dedicated to the issue of lithium exploitation, where, as far as I know, the opinion of the competent mining profession was not heard. In the effort to generalize the positions of the Presidency of the Academy of Engineering Sciences of Serbia as the stance of engineers in Serbia, it is not noted that the Department of Mining, Geological, and System Sciences distanced itself from the positions of the Presidency." These words confirm the claim that the same hand wrote both statements, from SANU and the Academy of Engineering Sciences.

Listing the nonsense and lies spoken about the Jadar Project could take a long time. In conclusion, we present a few of the most nonsensical statements about this project, which anyone with at least a little sense would be ashamed of. The writer and director Vida Ognjenović stated (Ognjenović, 2024): 'The mine will start operating. A foreign corporation will triple the return on invested funds and will sell lithium as its own product. A dozen survivors with some deviations will be kept in a strictly guarded facility on Stara Planina. And the few who can speak, with all the deviations caused by the toxins, will continue their debate about lithium..." According to the 2022 census, Serbia had 6,664,449 inhabitants. And imagine that someone, even if they were a director or a writer, could claim that 6,664,439 people in Serbia would perish from lithium, and only a dozen would survive "with some deviations." All that remains is to ask whether anyone with even a little bit of common sense could make such a ridiculous statement? The director is a Nobel Prize-worthy inventor because, until now, no one has known of anyone who invented a weapon for such massive destruction.

Equally nonsensical is the statement made by director Goran Marković: "Only if we are not covered with drill holes, which, with the help of chemicals, extract the Earth's guts and turn the fertile and forested landscapes of Serbia into a desert, do we have a future. If people give in now to the unscrupulous interests of capital and the local corrupt government – we are finished" (Marković, 2024). The director knows everything, even that they will extract the Earth's guts using chemicals and turn Serbia (fertile and forested) into a desert. This example shows that ignorance does not prevent people from spouting nonsense, which any reasonably minded person would be ashamed of. These examples illustrate how ignorance is well-distributed among writers, directors, filmmakers, and actors... The only comment for such nonsense is the Latin saying: *"Beati pauperes spiritu."*

One of the main questions in this whole fuss about lithium in Serbia remains: Why has much of Serbian "intelligence" not come together and worked to find the best solution for Serbia, both in terms of environmental protection and the economy, so that everything would be to the benefit of Serbia? How come a smaller, but fervent part of the Academy, that is, Serbian science itself, has been so engaged, and continues to be engaged, in trying to stop the lithium project in Serbia? Imagine if all that Serbian "intelligence" and all that "knowledge" about mining and extracting lithium had been harnessed and dedicated to solving all those "problems" they cite. Serbia would have the safest mining and lithium extraction in the world. But that did not happen, nor will it, because it does not align with the slogan around which all of them have gathered: "Let everything stop in Serbia."

What needs to be done

The author of this text proposed in his writings (Simonović, 2023) that "the Government should appoint a working group composed of people from universities and institutes with different profiles (mining-geological, hydrological, agricultural, as well as chemists, physical chemists, technologists, mechanical engineers, biologists, etc.) who, based on all available documents or additional ones that could be prepared, and based on scientific literature and global experiences in this field, would propose a decision to the government regarding this project."

Recent regulations and decisions made by the EU should also be taken into account, primarily the adherence to the standards for responsible mining (*IRMA* standard), which prescribe the conditions for responsible mining (environmental protection, social responsibility, etc.) (Initiative for Responsible Mining Assurance, 2023). Compliance with this standard should be a condition for the implementation of the Jadar Project (Simonović, 2024b). Furthermore, the EU Resolution on Sustainable Products (REGULATION (EU), 2024) and EU regulations on the digital product passport (Commission Europa, 2024) should also be considered. Along with all of this, there must be mandatory compliance with all domestic and EU regulations on environmental protection.

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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

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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

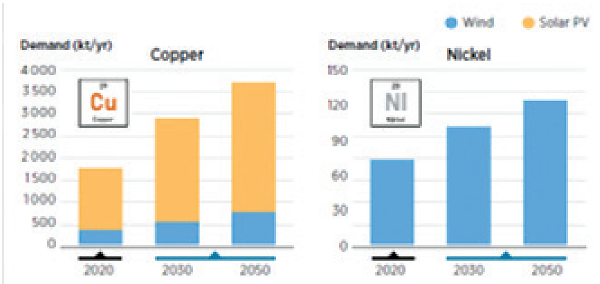

Figure 1: Projected demand for copper and nickel under the IRENA 1.5°C scenario (IRENA, 2022)

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.

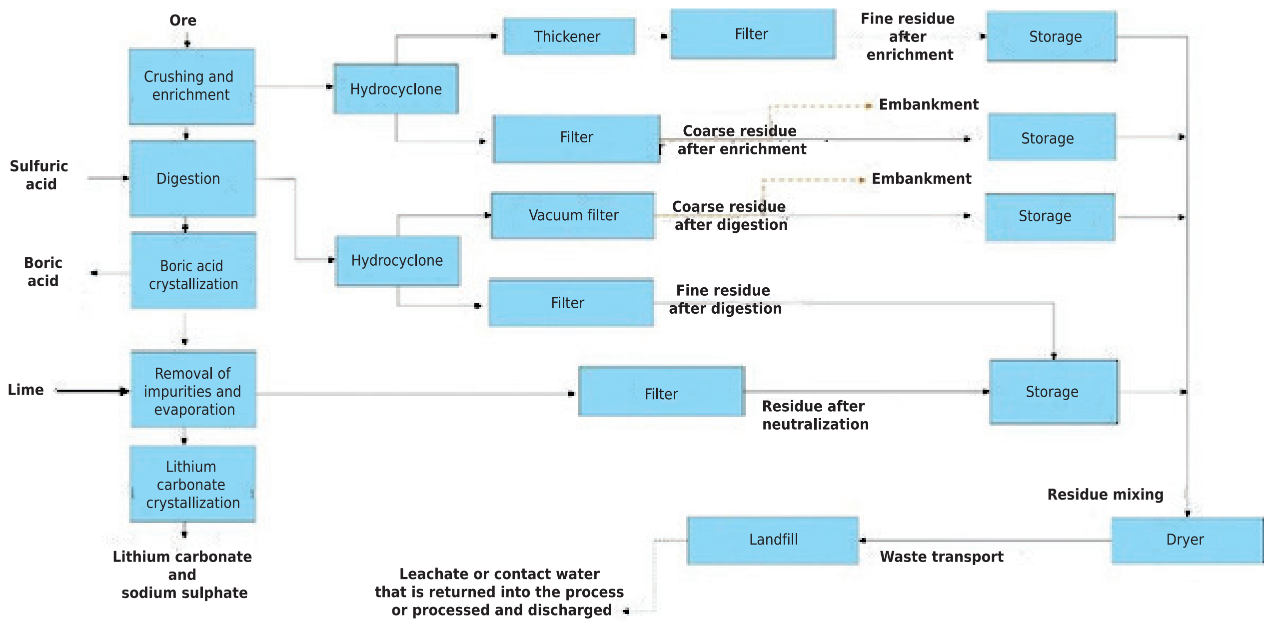

Figure 2: Simplified technological diagram of ore processing (MF, 2023b)

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 H2S 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;

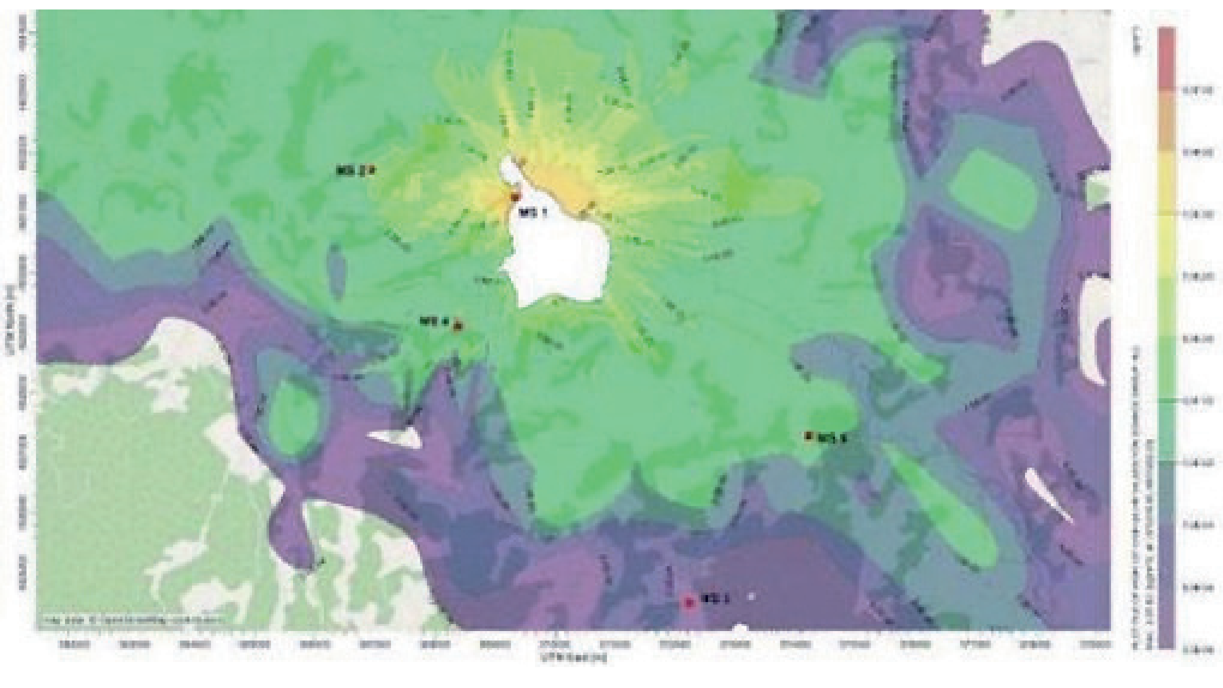

Figure 3: Maximum ground-level concentrations of H_2SO_4 for a one-day averaging period [µg/m³] (MF, 2023a).

- ✓ 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

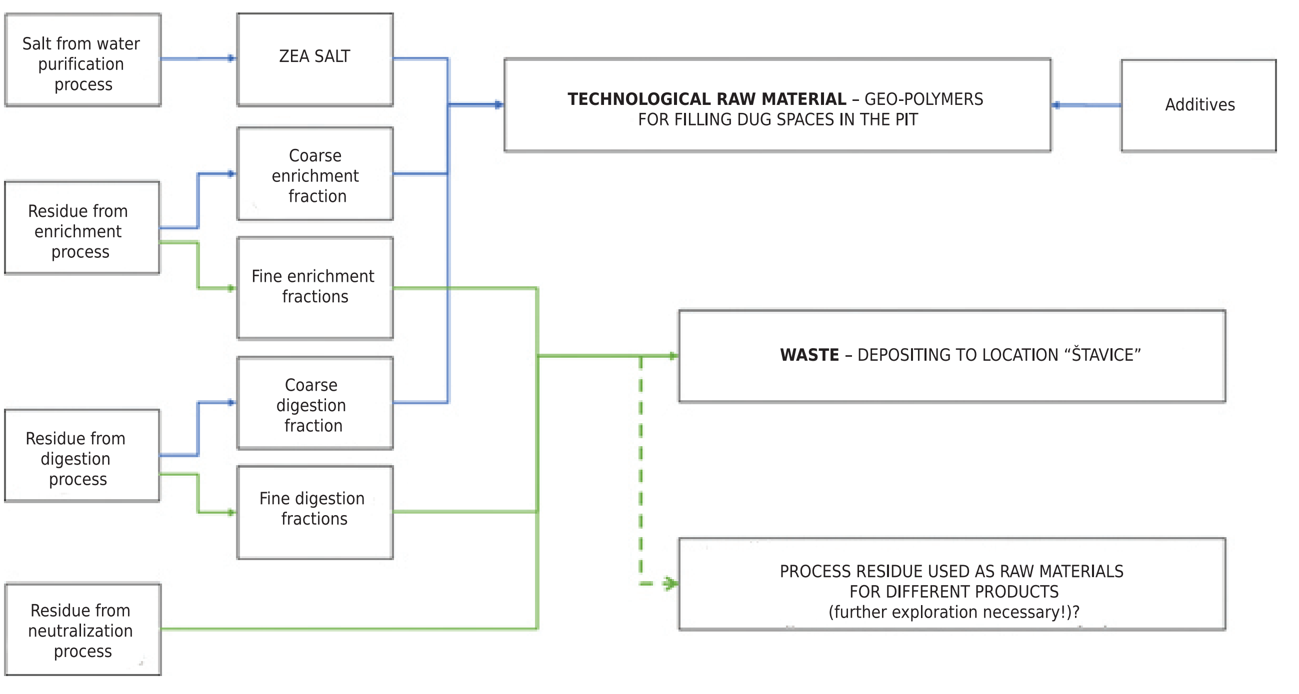

Figure 4: Principle of waste management from the processing of jadarite ore (MF, 2023b).

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).

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

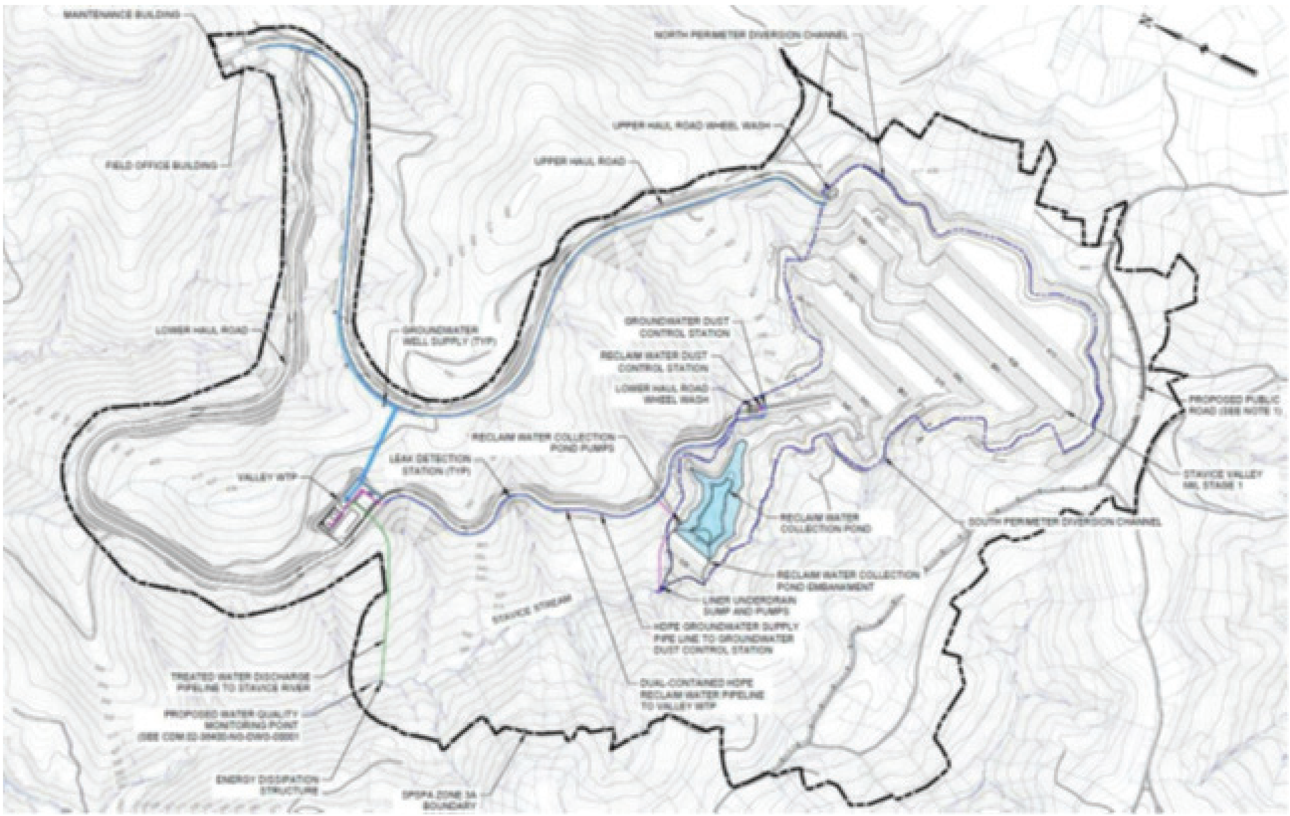

Figure 5: Layout of the industrial waste landfill (MF, 2023b)

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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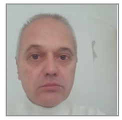
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Risks of Lithium Ore Mining and Their Mitigation

Abstract: Lithium is a key mineral for modern technology and the global energy transition. Its use in batteries for electric vehicles, smart devices, and renewable energy storage systems makes it an indispensable resource. However, the extraction process poses significant risks to the environment, local communities, and worker health. Water consumption, land degradation, pollution, and displacement of populations are among the most common challenges. The Jadar Project in Serbia represents a potential positive example of sustainable mining practices. This paper analyses the main risks and mitigation measures, including technological innovations, land reclamation, and community involvement.

Keywords: lithium, mining, mitigation measures, reclamation, environmental risks

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1. Introduction

Lithium has become one of the most significant metals of the 21st century due to its essential role in modern technological and energy transitions. Lithium is a soft, silvery-white alkali metal found in the second period of the Periodic Table. It is an extremely light metal with the lowest density among all solid elements (under standard conditions), making it the least dense of all solid elements. Its use in batteries for electric vehicles, smartphones, portable devices, and renewable energy storage systems has made it a strategic resource. The demand for lithium is growing exponentially, with forecasts suggesting that by 2050 the need for this metal will increase more than fivefold compared to current levels. In the context of combating climate change, lithium is a key element in the production of batteries for storing energy from renewable sources such as solar and wind power. Additionally, the development of electric vehicles as a replacement for fossil fuels depends on a stable supply of this mineral resource. This thesis has placed lithium at the centre of attention for global economies and spurred geopolitical aspirations to control its reserves. The discovery of jadarite in Serbia—a unique mineral containing lithium and boron—represents a significant potential for economic progress. The Jadar Project by the company Rio Tinto, one of the largest mining ventures in the region, aims to position Serbia among the world's leading lithium producers. However, this project has sparked numerous controversies due to its potential environmental and social impacts. The main challenges of lithium mining include land degradation, water consumption, pollution, and potential conflicts with local communities. Examples from Chile, Australia, and Argentina demonstrate that mining activities can significantly affect ecosystems and local populations if not accompanied by sustainable practices.

This paper aims to provide a comprehensive overview of the risks associated with lithium mining, as well as opportunities for their mitigation. Particular emphasis is placed on the application of modern technologies, such as closed water recycling systems and risk monitoring sensors, which can significantly enhance safety and reduce environmental impact. To improve environmental sustainability, projects like the Jadar Project can integrate environmental protection measures, including land reclamation after exploitation and community support programmes.

Through the analysis of risks and proposals for their mitigation, this paper seeks to contribute to a deeper understanding of the complexities of lithium mining and its impact on society and the environment. The goal is to identify steps that will enable the sustainable exploitation of this critical resource while minimising negative consequences.

2. Environmental risks from ore extraction

Water consumption

In arid regions, such as the Atacama Desert in Chile, water consumption often exceeds available water resources, leaving local communities without sufficient water for agriculture and daily needs, while in areas richer in water resources, mining operations frequently discharge water into local rivers. In regions with weak wastewater management systems, toxic materials can infiltrate aquifers, threatening the survival of ecosystems. The use of filtration systems and closed water recycling systems helps minimise this risk.

Soil degradation

Underground mining offers significant advantages over surface mining when high-quality design decisions are made regarding the method of lithium ore extraction. In many cases, soil degradation results in the inability to restore the land without extensive rehabilitation projects. The application of land reclamation, which involves planting native vegetation and stabilising the soil, can significantly improve existing conditions, though the process is time-consuming and costly.

Air pollution

During excavation, dust particles are released into the mine air, potentially causing allergies and respiratory illnesses. This can be effectively mitigated through the use of modern ventilation systems in underground mining operations.

Water pollution

Mine water often enters local waterways. In areas with weak wastewater management systems, toxic materials can penetrate aquifers, threatening ecosystem survival. The use of filtration systems and closed-loop water systems helps minimise this risk.

Loss of biodiversity

The destruction of natural habitats due to mining has a direct impact on local flora and fauna. In the Atacama region, bird and insect populations have decreased by 30% due to the loss of natural food and water sources. Additionally, large transport routes constructed to access mines accelerate habitat destruction.

Conservation programs for endangered species, such as compensatory habitats, have proven effective in mitigating these effects, but they require significant financial investments.

3. Social, economic, and health risks

Social and economic risks associated with lithium ore mining often stem from the complex dynamics between mining companies, local communities, and national economies. While mining offers potential economic benefits, including job creation and increased state revenue, it also presents numerous social challenges that require careful consideration.

Displacement of communities and social tensions

One of the most significant social risks of mining activities is the displacement of local communities. In many cases, mining companies acquire land belonging to local populations, forcing them to leave their homes and abandon traditional sources of income. This is often accompanied by social tensions, dissatisfaction, and protests. An example from Bolivia illustrates how a major mining project led to prolonged conflicts between the company and indigenous communities.

Figure 1 – Bolivia, the country with the largest lithium reserves in the world (BIZLife, 2023)

In Serbia, as part of the Jadar Project, the company Rio Tinto has conducted public debates and compensation programs to mitigate social tensions. Such programs include the relocation of affected families, as well as financial assistance to help them find new sources of income. In addition, investing in local infrastructure, such as schools, hospitals, and roads, can significantly contribute to reducing conflicts.

Economic dependency and instability

Economic dependence on mining poses a long-term risk for many countries that rely on lithium ore exports. The volatility of prices on the global market makes economies dependent on mineral resources vulnerable to changes. Chile and China are such examples, where large fluctuations in lithium prices have affected the national budget and economic stability.

Lithium prices on the global market show significant volatility, which directly affects the economies of countries that rely on exports of this metal. For example, between 2020 and 2022, the price of lithium rose from USD 6,320 to USD 71,500 per ton, followed by a decline of around 80% since the end of 2022 (RTBalkan, 2024).

For instance, if the price of lithium today suddenly rises due to increased demand for electric vehicles, and then sharply falls tomorrow due to the discovery of new reserves, this is an example of high volatility.

To reduce this risk, economic activity diversification is required. In Serbia, as part of the Jadar Project, investments are planned in local high-tech industries that could reduce economic dependence on mining. To achieve this, the construction of a lithium-ion battery factory is planned, followed by the production of electric vehicles. Additionally, part of the revenue from mining could be invested in the development of educational and research centres that will encourage innovation and ensure a sustainable economy in the future.

Land right disputes

These are common in mining regions, especially when local communities lack clear legal documentation of their property. In some cases, this leads to prolonged legal disputes that can halt or delay mining projects. In the Jadar Project, the company has focused on purchasing land at fair market prices to avoid legal and social conflicts.

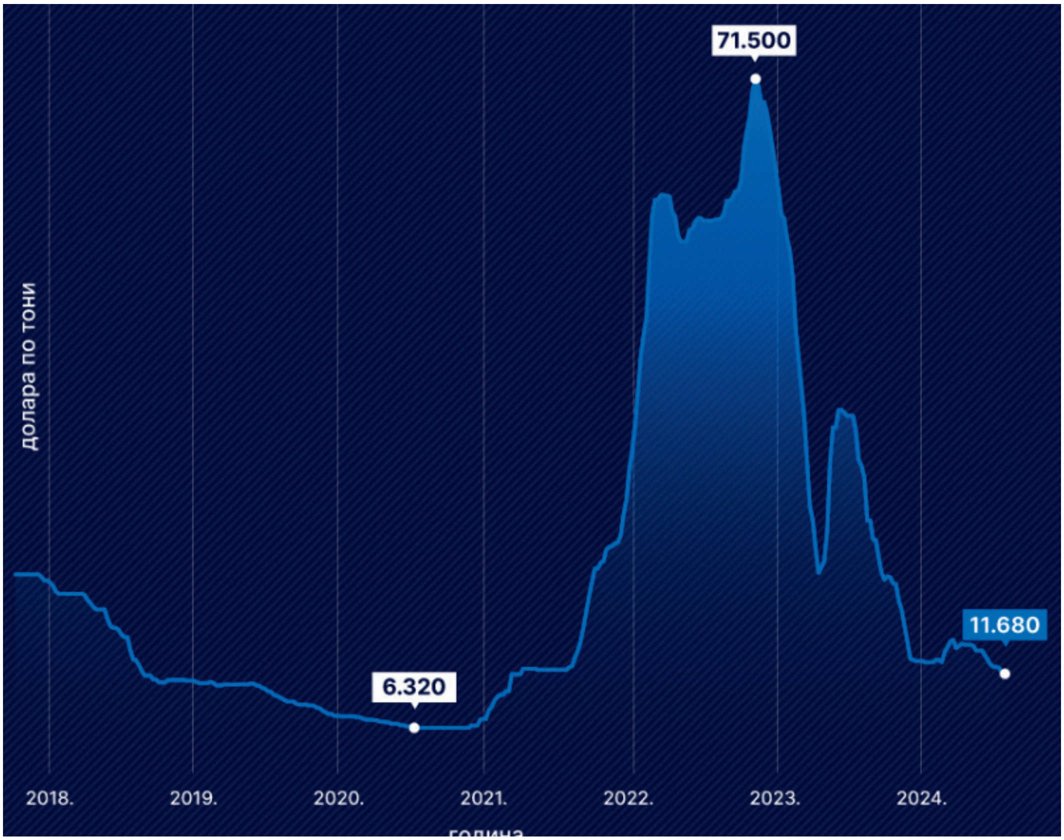

Figure 2 – Lithium price chart on the Chinese stock exchange (RTBalkan, 2024)

Social programmes as a solution

To mitigate social risks, many companies introduce corporate social responsibility programmes. These programmes include investment in education, healthcare, and the development of local businesses. In the Jadar Project, one of the goals is to invest in environmental education for the local population, as well as provide training for workers who will be engaged in the mining and production sectors.

Health risks

Workers and the local population may be exposed to health risks due to mining activities.

Exposure to toxic substances: contact with chemicals used in the extraction process can lead to health issues for employees engaged in production.

Respiratory problems: dust and emissions from mines can cause respiratory diseases.

Workplace accidents: mining is inherently a dangerous occupation with a high risk of injuries.

Environmental measures

Water recycling reduces consumption by 40% (Marković, 2009). The use of less toxic chemicals, such as biodegradable substances (RenovablesVerdes, 2024). Installation of air and water purification systems.

Social measures

Involving local communities in the decision-making process. Compensation programs for affected families. Investment in local infrastructure, including schools and hospitals.

Technological measures

Risk monitoring systems, such as gas sensors and early warning systems, reduce risks in underground mines. The use of advanced algorithms and GIS technologies enables more efficient planning of mining operations (Rudarstvo.org, 2024)

5. Land reclamation after exploitation

This is a key step in reducing the negative effects of mining activities. The main purpose of reclamation is to restore the land to a condition that allows its reuse,

Aerial view of lithium fields in the Atacama desert in Chile, South America - a surreal landscape where batteries are born.
Photo: Shutterstock

whether for natural ecosystems, agriculture, or recreational purposes. In lithium mining, where the focus is often on sensitive ecological regions, this process becomes even more significant. (Envirotis Holding)

Application of reclamation in the Jadar Project

This project in Serbia is an example of a planned approach to reclamation. After the completion of mining activities, it is planned that part of the land will be prepared for agriculture, while other areas will be reforested with local plant species, such as oak and acacia. This ensures not only ecological sustainability but also economic benefits for the local population (Rio Tinto, 2019).

Examples of successful reclamation

Ruhr region, Germany:

Former coal mines in the Ruhr area have been transformed into public parks and lakes, which are now tourist attractions. Reclamation involved removing toxic materials, constructing new infrastructure, and creating habitats for local wildlife species.

Atacama Desert, Chile:

In this region, parts of abandoned mines have been converted into birdwatching centres. By using natural reclamation techniques, such as recharging aquifers, mining companies have managed to restore parts of the ecosystem.

Mineral Jadarite, Natural History Center of Serbia Svilajnac.
Photo: Shutterstock

Greenbushes, Australia:

This lithium mine implemented biological reclamation in collaboration with local scientific teams. Planting eucalyptus trees and establishing new natural habitats contributed to the rapid recovery of the land.

Technical aspects of reclamation

The reclamation process often includes:

Technical remediation: stabilising the terrain, removing toxic materials, and levelling the land; Biological remediation: planting local plant species to restore the natural ecosystem; Ecological monitoring: tracking reclamation results over an extended period to ensure the stability of new ecosystems.

Challenges and costs

Reclamation is a highly expensive process. It is estimated that reclamation costs can account for up to 20% of the total costs of a mining project. Nevertheless, the long-term benefits, including reduced environmental risks and improved quality of life for local communities, justify these costs.

6. Conclusion

Lithium extraction presents challenges but also opportunities for significant economic and technological progress. By implementing sustainable practices and adhering to all domestic and EU environmental regulations, as well as IRMA standards for responsible mining, it is possible to minimise environmental, social, and health risks. The Jadar Project in Serbia serves as an example of a responsible approach that incorporates modern technologies, transparency, and collaboration with local communities. Through water recycling, the use of less toxic chemicals, advanced ventilation systems, and land reclamation, lithium mining can become a model for sustainable development in the industry. However, continued innovation and investment in research are essential to develop new technologies that further enhance this sector.

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The Public Health Importance of Monitoring Surface Water, Soil, Air, Biological Monitoring and Sustainable Mining

Abstract: Modern technological advancements in mining involve the implementation of environmental standards and protective measures that significantly contribute to preserving natural resources and preventing potentially harmful impacts on the environment. These advancements enable early identification and minimisation of risks. The mining industry plays a vital role in the economic development of society while simultaneously adhering to strategies for environmental preservation and public health protection. This is achieved through modern methods for monitoring environmental parameters and population health. Mining and geological exploration may lead to the presence of potentially toxic elements (PTEs), which in certain concentrations across various environmental media pose challenges to both the environment and human health. Environmental monitoring is a crucial strategy for achieving sustainable mining. Sustainable mining development through effective monitoring of water, soil, air, and biological indicators in mining areas ensures the preservation of ecological balance and public health in regions where mineral exploitation occurs.

Keywords: mining, monitoring, surface water, soil, air, bio-monitoring

Foreword

Mining represents a key industrial sector that significantly contributes to the development of society, the economy, and technology. The extraction of minerals and metals provides essential resources for numerous industries, including construction, electronic equipment production, transportation, and renewable energy sources. This sector also drives technological innovations and infrastructural

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development, promoting societal modernisation. Given the importance of preserving natural resources and protecting the environment, mining activities are conducted following the most advanced regulations and measures to ensure sustainability. These include environmental protection strategies, public health safeguards, and occupational safety and health measures for workers in the industry. Relevant institutions and various sectors, including multiple ministries, actively contribute to integrating environmentally responsible practices at all stages of mining processes. This approach seeks to balance economic growth with the preservation of natural ecosystems, ensuring the long-term protection of public health and the environment. Thanks to such initiatives, mining remains indispensable for sustainable economic and technological progress while necessitating continuous environmental monitoring.

The public health aspect of mining pertains to identifying, monitoring, and managing health risks associated with mining activities to preserve both the environment and human health. This includes assessing the impact of mining processes on the quality of surface water, soil, and air through integrated monitoring systems. Broadly speaking, monitoring is essential across many disciplines, from environmental protection and industry to healthcare and public policy, as it enables decision-making based on reliable data. Monitoring is defined as the continuous process of overseeing, observing, and collecting data about a particular process or condition to draw relevant conclusions (Knežević et al., 2015). Some of the approaches to controlling the environmental impact of mining, relevant to public health, include comprehensive environmental monitoring, soil monitoring, water monitoring, air monitoring, and biological monitoring.

Environmental monitoring in a broader sense refers to a systematic process of collecting and analysing data on selected parameters characterising the state of the environment to detect changes in a timely manner, support decision-making, and prevent adverse environmental impacts (Ehlers & Kastler, 2009; European Commission [EC], 2003). In the Republic of Serbia, public health significance is prioritised through monitoring parameters such as water, soil, and air quality, as well as biological monitoring. When planning environmental monitoring and selecting parameters, it is necessary to consider environmental characteristics and potential hazards, including their sources, spread, changes, and potential recipients. During ore extraction, especially of metallic ores, one anticipated hazard is the release of metals and metalloids classified as potentially toxic elements (PTEs). Monitoring methods and parameters for PTEs depend primarily on the medium (soil, water, air, or biological material) where these pollutants are tracked. Continuous exchange of substances occurs between water, sediments, soil, air, and living organisms, requiring each of these media to be included in the monitoring plan (Nieder, 2024).

Monitoring the quality of water, soil, and air in mining areas is an important element of public health strategies, which affect the preservation of the environment and public health within a multidisciplinary approach to monitoring risk factors for human health. In addition to the aforementioned types of monitoring, biological monitoring stands out as an additional method significant for assessing the cumulative potential impact of risks originating from mining processes on the environment and potential effects on human health.

The aim of this paper is to examine the key elements and methods of environmental monitoring (surface water, air, soil) with the goal of preserving public health in Serbia, including potential methods of biological monitoring in mining areas and their application in assessing risks to human health.

> The public health aspect of mining pertains to identifying, monitoring, and managing health risks associated with mining activities to preserve both the environment and human health.

Regulations governing the environmental monitoring process in the context of mining activities

The environmental monitoring process in the Republic of Serbia, in the context of mining activities, is regulated by a series of laws, by-laws, and regulations aligned with international standards and European Union (EU) directives. Key regulations include the Law on Environmental Protection (Official Gazette of RS, no 135/04, 36/09, 36/09 – other law, 72/09 – other law, 43/11 – CC, 14/16, 76/18, 95/18 – other law, 94/24 – other law), which defines obligations for monitoring air, water, soil, and biodiversity quality, as well as procedures for environmental impact assessments and strategic environmental assessments. The Law on Mining and Geological Exploration (Official Gazette of RS, no 101/15, 95/18 – other law, and 40/21) mandates environmental oversight and remediation during and after the exploitation of mineral resources, along with the preparation of environmental impact studies. The Law on Water (Official Gazette of RS, no 30/10, 93/12, 101/16, 95/18, 95/18 – other law) regulates the protection and sustainable use of water resources, including the regular monitoring of surface and groundwater quality near mining facilities.

The Environmental Impact Assessment Law (Official Gazette of RS, no 94/24) prescribes procedures for assessing the environmental impact of projects, including the use of public hearings, conclusions from expert panels, and continuous monitoring during project implementation. The Waste Management Law (Official Gazette of RS, no 36/09, 88/10, 14/16, 95/18 – other law, and 35/23) regulates the management of mining waste and the monitoring of potential pollution from tailings and other waste materials.

The Republic of Serbia aligns its regulations in this field with EU directives, enabling the application of the highest environmental protection standards in the mining sector. Key institutions overseeing the implementation of monitoring include the Environmental Protection Agency, the Ministry of Environmental Protection, and the Environmental Protection Inspection, as mandated by Serbian regulations.

The implementation of legal provisions in the field of monitoring contributes to reducing the potential negative impact of mining activities on the environment and public health, enables the timely identification and elimination of potential risks, and supports sustainable development and the protection of natural resources.

The Public Health Law of the Republic of Serbia (Official Gazette of RS, no 15/16) defines the preservation of public health and the application of all environmental monitoring strategies as a key obligation of the state to ensure its protection.

Elements of environmental monitoring

Environmental monitoring is based on tracking specified parameters, which can be qualitative or, more commonly, quantitative. In environmental monitoring, chemical, physico-chemical, and biological parameters are most frequently tracked. Predefined parameters can be measured or determined in situ or by sampling followed by subsequent analysis. Depending on the nature of the parameters, their values can be measured continuously or intermittently (Ruppen, 2021). The monitoring plan must define the geographical area where monitoring is conducted, the parameters being tracked and the medium (environment), the plan and method for direct measurement or sampling, the conditions for storage and transportation of samples, sample processing, sample analysis, the plan for data processing, the plan for data analysis, and the method of presenting and disseminating results.

In the environmental monitoring process, it is essential to provide and plan the development of standard protocols for each monitoring phase, train personnel conducting the monitoring, ensure logistical conditions for monitoring implementation, and obtain appropriate accreditation and certification for institutions carrying out the monitoring (EC, 2003; Modoi, 2014).

Monitoring of surface water, soil, and air

These types of monitoring are essential for the preservation of public health. Protecting public health involves safeguarding the environment as well as maintaining the health of the population. Precisely defining the area under investigation and its characteristics is crucial for the effective implementation of these monitoring activities (Loredo et al., 2010). Defining the geographical area requires knowledge of its size and exact location. For surface water monitoring, it is also necessary to map the entire watershed, including the tributaries of water bodies located in mining areas (Wei et al., 2018). Additionally, it is essential to determine the position of water body segments relative to the sites/areas of ore extraction and processing, as well as waste disposal, and to define which sections are upstream and which are downstream of these locations (Modoi, 2014; Jiménez-Oyola et al., 2023; Ruppen et al., 2021).

For professionally conducted water monitoring, it is crucial to understand the composition and structure of rocks, soil, and tailings, primarily due to their potential interaction with surface waters. Tailings are by-products of mining processes, specifically ore extraction and processing, in the form of liquid sludge or suspensions. It is important to note that the chemical composition of suspended particles depends on the composition of the ore, rocks, and soil, as well as the chemicals used during ore processing. For this reason, the properties of tailings will depend on their composition, acidity, salinity, particle size distribution, solid matter content, and consistency (Gorakhki & Bareither, 2016; Wang et al., 2014). Responsible management of waste generated during ore extraction is an integral part of the mining process. Proper waste management during ore extraction is a highly significant preventive measure in environmental protection and an imperative practice for sustainable mining.

It should also be emphasised that the description of the characteristics of the mining area includes climatological data, primarily the average annual temperature, precipitation amount, and seasonal distribution of precipitation (Loredo et al., 2010). The amount of precipitation affects biogeochemical processes in the soil, and during prolonged dry periods, it can lead to a decrease in soil acidity and further mobilisation of potentially toxic elements (PTE), causing them to transition into water (Modoi et al., 2014). A significant parameter for effectively conducting water monitoring is the flow rate in running waters, which is also closely related to climatic parameters (Nordstrom, 2011).

In monitoring the quality of surface waters in mining areas, the concentration of substances of interest for a specific type of mine is primarily monitored. The defined parameters are tracked intermittently, through water sampling and subsequent analysis of samples. Additionally, parameters such as pH and electrical conductivity are monitored in situ, through direct measurements, which can be either intermittent or continuous by setting up appropriate sensors and automatic data logging systems (Ruppen et al., 2021). For the surface water monitoring process, it is essential to define the exact sampling locations (sampling network), the time and frequency of sampling (sampling schedule), as well as quality control of sampling (Behmel et al., 2016; Jiang et al., 2020).

When preparing a soil monitoring plan, the soil type should be determined based on particle size (sand, silt, or clay), which represents the first step in the analysis. Additionally, monitoring the soil pH is extremely important, along with examining the chemical composition, including the content of organic matter, which significantly influences the soil properties in soil monitoring. Special attention should be given to the content and forms of elements such as aluminium (Al), iron (Fe), and manganese (Mn), as their oxides often serve as centres for the co-precipitation of other elements, which can indicate their behaviour in the soil (Rinklebe et al., 2019). It is important to know that the toxicity, mobility, and biological availability of potentially toxic elements (PTEs) are influenced by their form, or speciation, which depends on biogeochemical processes in the soil that, in addition to pH, are affected by numerous parameters, including some elements resulting from microbial activity (Frohne et al., 2014; Ponting et al., 2021).

According to Rinklebe and colleagues, when planning sampling, in addition to defining the location and time, it is essential to understand the soil profile and define the depth from which the sample is taken (Rinklebe et al., 2019). Additionally, Nieder and Benbi note that the concentrations of elements in soil particles are in constant equilibrium with the water present in the soil pores, making them available to living organisms (Nieder & Benbi, 2023). Due to this dynamic of potentially toxic elements (PTEs) between the soil and water, it is necessary to map the hydrological characteristics of the area and record potentially flooded areas (Ponting et al., 2021). According to available literature, innovations in soil monitoring are driven by the rapid development of sensors and their application. However, sampling and subsequent sample analysis are still the methods that are routinely applied.

The main challenges related to the mining industry concern mining waste dumps that can impact the environment. Due to their chemical nature, which includes a lack of nutrients and a high concentration of metals and metalloids, mining waste dumps (landfills) can potentially have a negative impact on the environment, making safety measures in waste management processes extremely important. One of the effects of mining activities is soil degradation, which is particularly evident near mining sites (Ali et al., 2021). In these areas, the soil may potentially be contaminated with heavy metals and metalloids, so such phenomena must be prevented. Modern methods of mining waste disposal include fraction separation, as well as thickening, dewatering, and compacting tailings (waste), which can reduce the potential environmental impacts of mining waste (Furnell et al., 2022; Onifade et al., 2024).

According to the Air Protection Act (Official Gazette of the RS, no 36/09, 10/13, and 26/21 – amended law), in order to ensure effective air quality management, an integrated system is established for monitoring and controlling pollution levels, as well as for maintaining a database on air quality, known as air quality monitoring.

Air quality monitoring is one of the key instruments whose application contributes to the protection of public health and the environment. This practice is especially important in mining areas where industrial activities can significantly affect the concentration of pollutants in the air. The air quality monitoring system establishes a national and local network of measuring stations and/or measurement points for fixed air quality measurements. Mining activities are among the most significant human activities that can contribute to dust and aerosol emissions, depending on the type of mine, covering large areas globally, and involving the presence of potentially toxic elements (PTE) (Csavina et al., 2012). The significance of air monitoring lies in the timely detection of increased concentrations of pollutants, which enables quick interventions and the implementation of measures to protect the population. It is particularly important to emphasise that regular air quality monitoring allows for the assessment of long-term trends, thereby contributing to strategic planning and improving public health in Serbia.

Biological monitoring and mining

Biological monitoring is a method of tracking the concentration of specific parameters and is an important approach for assessing the impact of pollutants, such as potentially toxic metals and metalloids, on human health and the environment in mining areas. Mining activities often lead to the release of potentially toxic elements (PTEs), such as arsenic (As), cadmium (Cd), lead (Pb), as well as silver (Ag), mercury (Hg), and zinc (Zn) (Rakete et al., 2021). The use of biological monitoring allows for the identification of the presence of metals and metalloids and the assessment of the level of exposure of living organisms.

Biological monitoring is the continuous, long-term, or periodic tracking and assessment of biological and ecological changes (parameters) using specific methodological approaches (Hirvonen, 2008). Additionally, biological monitoring is the use of living organisms as bio-indicators of changes in the environment over space and time. The term "bio-indicators" was first introduced by Clements in 1920 to refer to organisms whose presence in a specific habitat indicates the ecological conditions of that habitat. For methodological reasons, biological monitoring is divided into different categories depending on the type of environment in which changes are monitored, including: air monitoring (where lichens and mosses are used as bio-indicators); aquatic environment monitoring (with bio-indicators such as algae, bacteria, fish, and other organisms indicating changes in water quality); and soil monitoring (where plants, i.e., vegetation, are used as bio-indicators) (Metcalfe, 1989).

Also, occasionally and most often of a project-based nature, analyses of biological samples in the human population are conducted. For such methods, special consent from the subjects or the existence of legal regulations is required. In these cases, based on the analysis of biological samples such as blood, urine, hair, or saliva in the human population, it is possible to track the cumulative impact of these contaminants on the health of the population, as well as on ecosystems in the immediate vicinity of mining areas (Molina-Villalba et al., 2015; Rakete et al., 2021).

According to Nagajyoti, heavy metals and metalloids present in the soil cannot be degraded due to their persistence and stability, but instead bio-accumulate, gradually entering plants, animals, and humans through the air, water, and food chain (Nagajyoti, 2010). Arsenic, cadmium, hexavalent chromium, copper, lead, methyl mercury, nickel, and zinc are heavy metals that have the ability to bio-accumulate (U.S. Environmental Protection Agency [EPA], 2000). Additionally, according to the data from the Environmental Protection Agency (EPA), the bio-accumulation process is accompanied by bio-magnification, where concentrations of harmful substances increase as they move up the food chain, with predators at the top of the chain being most at risk due to consuming large amounts of contaminated organisms (EPA, 2021). Bio-magnification factors represent the ratio of metal concentration in the predator's body compared to its prey, clearly tracking how metals move through the food chain and increase in concentration in the predator's organism (Ciesielski et al., 2006).

Today, in the Republic of Serbia, in accordance with regulations, the aforementioned types of monitoring in mining areas are key protective strategies for the preservation of the environment and public health as a whole.

In the context of surface waters and soils in mining regions, biological monitoring is used to identify pollution sources and assess their long-term effects (Costa & Teixeira, 2014). Specific organisms, such as fish, plants, and microorganisms, known as bio-indicators, enable early recognition of pollution in water and the presence of pollutants, which helps in assessing its consequences on the stability of ecosystems (Cakaj et al., 2024; Chovanec et al., 2003).

Biological monitoring is also, though very rarely, used to assess the exposure of the local population, particularly in areas where mining activities are conducted, which can potentially lead to increased concentrations of PTEs in the environment, in order to assess health risks for both mine workers and the local population (Michalak & Chojnacka, 2014). The use of biological monitoring in mining areas contributes to a better understanding of the ecological and health risks associated with potentially toxic elements, thus enabling more effective environmental monitoring (EPA, 2022). Such application of the monitoring is carried out sporadically.

Sustainable development of mining and measures for environmental protection and public health

According to the literature, from a public health analysis perspective, there are two basic methods of ore extraction: surface and underground.

Surface mining, according to the literature, provides greater efficiency and safety, but it can potentially disrupt environmental balances. Underground mining is more environmentally acceptable (Sahu et al., 2015).

Considering the facts mentioned so far regarding monitoring in various media, most authors define sustainable mining or sustainable development of mining as a practice that achieves a balance between economic, ecological, and social factors (Laurence, 2011). It is concluded that sustainable mining development involves achieving a balance between economic viability, technical feasibility, environmental responsibility, and social impact, with a focus on integrating the concept of sustainability into decision-making strategies (Pavan Kumar, 2014). Minimising environmental impact at all stages of the mine's life cycle is crucial for supporting sustainable mining development, which is achieved through effective environmental management (Hilson & Murck, 2000). According to Laurence, safety in mining is achieved through responsible risk management, efficient monitoring and reporting systems, continuous education, training, and capacity-building of the workforce employed in mining, as well as equipment and work processes (Laurence, 2005). All of these activities represent measures that contribute to the protection of the environment and public health, thereby ensuring the long-term sustainability of mining projects.

Before the start of mining operations, the first and most significant measure is conducting an environmental impact assessment study, which is applied to projects in industries such as mining, energy, transport, tourism, agriculture, forestry, water management, waste management, public services, as well as projects in protected natural and cultural heritage areas. According to the Law on Environmental Impact Assessment (Official Gazette of RS, no 135/04 and 36/09), the environmental impact assessment study analyses the quality of the environment, sensitivity in a particular area, the impacts of existing and planned activities, and measures to prevent harmful effects on the environment and human health. Before opening a mine, the practice is that the company initiating the opening and operation of the mine is obliged to ensure that the study will thoroughly address and present all potential cumulative impacts of the project on the environment. More importantly, for each detected potential impact, it is necessary to explicitly list measures for its minimisation, as well as monitoring plans for various media. Monitoring both the environment and the health of the population represents key aspects of sustainable mining, where regular implementation and continuity must be ensured to timely identify and minimise potential negative impacts on the environment and human health.

Improving safety and sustainability in mining – modern practices

In recent years, global attention in mining has been focused on improving the legal frameworks that regulate safety in the mining sector. This progress is the result of collaboration between governments and international organisations, which are aware of the need for a modern approach to addressing new challenges and reducing the negative impacts of mining activities on the environment and human health.

The International Council on Mining and Metals (ICMM) represents one of the important initiatives and brings together leading global companies in the mining and metallurgy sectors. Their set of core business principles promotes responsible mining practices, environmental sustainability, and worker safety (International Council on Mining & Metals [ICMM], 2024). In recent years, the global trend has been the improvement of legislation in the mining sector. It has been noted that many countries at the national level are improving legislation to address local specifics and challenges within the mining industry.

In practice, companies in the mining sector implement various measures to ensure a safe working environment. This includes quality training programs to educate workers about the risks of mining work and protective and preventive measures, the application of modern technologies for automation and monitoring of working conditions in mines, as well as the use of personal protective equipment (Arbak, 2015; Agboola et al., 2020; Kursunoglu et al., 2022). In addition, creating effective emergency response plans and continuously monitoring the health of workers helps with prevention and timely treatment when necessary. A very important feature of responsible business practices in mining is also improving community awareness. Involving the local community in decision-making processes is also of great importance, and such actions by companies managing mines build trust and foster opportunities for cooperation between companies and communities.

Following the development of mining, as well as methods for monitoring various environmental parameters, the continuous advancement of technologies applied in this industry, and the integration of advanced technologies such as artificial intelligence and robotics, collectively reduce the level of worker exposure to hazards and optimise safety standards (Hyder et al., 2019). At the same time, the global trend towards sustainable practices in mining requires a reduction in potentially negative environmental impacts (Gorman & Dzombak, 2018). In light of the increasing demand for resources, the mining industry will have obligations to balance the sustainability of this sector, the protection of worker health, and market needs.

Conclusion

Responsible management of mining activities, particularly in the context of potential projects being implemented worldwide, as well as within the territory of the Republic of Serbia, requires a comprehensive approach that includes the application of the latest sustainable technological solutions in mining, the implementation of environmental protection measures, and transparent participation of all stakeholders in achieving responsible management of mining activities. A comprehensive approach involves the application of modern technologies, the improvement of regulations, and the strengthening of cooperation between states and companies operating in this industry. This approach is key to achieving responsible mining that is safe for workers, the population, and the environment. The application of best available techniques for waste management, water treatment, and control of GHG emissions in mining areas enables the minimisation of their potentially negative impact on the environment and public health. Continuous environmental monitoring and the involvement of local communities in monitoring information related to mining operations contribute to improving public awareness of the technologies applied and safety measures.

The integration of multi-sectoral cooperation between state institutions, scientific organisations, the civil sector, and local governments contributes to more efficient solutions to challenges or unforeseen events related to mining, while adhering to domestic and European standards in mining and environmental protection. In addition to technical measures, raising the level of awareness and consciousness among the population, as well as informing employees in this industry, plays a significant role in achieving the sustainability of mining and the preservation of natural resources and a safe environment.

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Book Reviews

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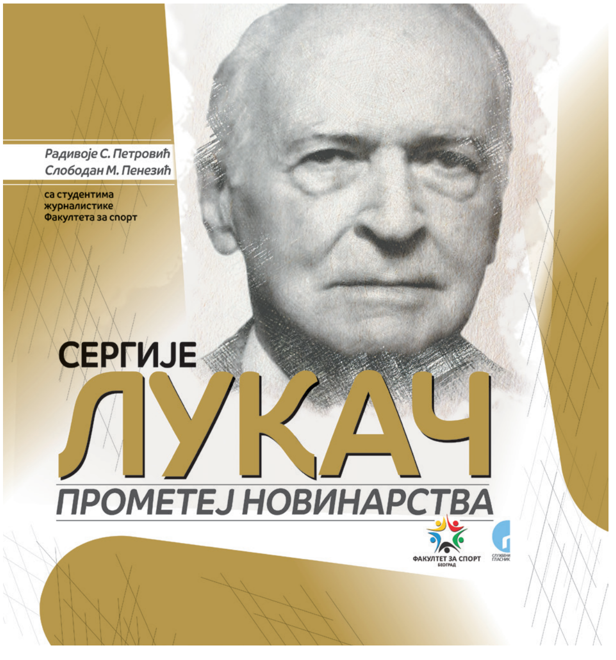
Timeless Journalistic Mission of Sergije Lukač

A monument to the favourite professor



Radivoje S. Petrović, Slobodan M. Penezić,
with the students of journalism
at the Faculty of Sport (2023).
SERGIJE LUKAČ – PROMETHEUS OF JOURNALISM.
Belgrade: Faculty of Sport,
University "Union – Nikola Tesla",
Službeni glasnik, 251 pages.

Professor Sergije Lukač's name has been present in my professional life since 1992, when as a student of journalism at the Faculty of Political Science I seriously entered the theory of media. Later on, as an already experienced journalist in Radio Belgrade, I had the opportunity to make an interview with him. Although we never work together, I learnt very much from Sergije Lukač and until recently I wondered how it was possible that there had been no monograph about the man made such a contribution to journalism and numerous generations of journalists educated at the Faculty of Political Science – the monograph

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which would somehow be a gesture of respect and gratitude for all the knowledge he selflessly shared. In that respect, the book *Sergije Lukač – Prometheus of Journalism*, co-authored by Professors Radivoje S. Petrović and Slobodan M. Penezić, is a special monument raised by the journalists to their professor.

This book consisting of seven chapters – "Forgotten model", "Journalist Bible", "Life stamp", "Long-distance sprinter", "Pledge to journalist descendants", "Thus wrote Serge", and "Walking on Lukač's path" – perceives Sergije Lukač's life and work from several perspectives. First of all, it is done through the journalistic prism, because Professor Lukač was primarily a journalist. He published 1,549 texts and worked in NIN for as many as 25 years. Another perspective on which the authors place their focus is Professor Lukač's academic work and the work of the Department of Journalism which he founded at the Faculty of Political Science in Belgrade in 1968. During his 17-year-long work, his lectures were attended by 17 generations of more than 1,000 students.

Furthermore, Petrović and Penezić also present Sergije Lukač through sport because it is well-known that "he treated sport as a virtue and a way of life", i.e., his character of an exceptional erudite, a polyglot, and a man dedicated to respecting ethical principles.

An added value to this comprehensive research paper is given by the memories of Lukač's contemporaries and closest associates, who do not separate his private and professional sides, but use that synergy to show the man respected by the entire public. The authors state multiple reasons for preparing this monograph. First of all, they find the monograph "an attempt to leave at least a written monument as a signpost to future generations for ultimate journalist knowledge and to those who have not remembered him for many years, an opportunity to repay, at least in part, a huge moral debt to their colleague, friend or professor". The other, also important motive is the opportunity to involve the students of sport journalist at the Faculty of Sport, University "Union – Nikola Tesla" in Belgrade, in material collecting and research. Namely, "apart from becoming familiar with his journalist work, they will be able to apply the experience acquired while working on the monograph in their further professional engagement", Radivoje Petrović and Slobodan Penezić emphasize, and I completely agree with them, that "Professor Lukač's thought is more important today than ever before, in the era of returning to traditional principles of journalism, when we are trying to restore the dignity of this profession and trust of the audience".

The monograph is not only a homage to the professor, journalist and erudite, but also a textbook of journalism. In fact, the whole work contains morals and advice of Professor Lukač, who proved that theory and practice could and had to go together. In the book, it is also confirmed by his assistant at the Faculty, Professor Neda Todorović, who points out that "the professor had a visionary understanding that these two roads were the only possible way of modern journalist education". The way of his seeing the journalist profession is perhaps described best by what Moša Pijade wrote in the past and the professor often quoted – that "a journalist spent half of his time writing about what he know nothing about, and the other half about what he knows but must not say". This monograph is not only a book for reminding all those who were Sergije Lukač's contemporaries, but also a guide for young journalists. That is why the authors very carefully and in the right places, with good examples of different situations from Sergije

Lukač's life, point to the central points of Lukač's so-called journalist Bible with the three most important things: "first, sufficient broad education, from which it is easy to delve into a specialized field; second, being familiar with the techniques of expression, media technology management and the feeling of measure in the emotional dosing of information; third, intellectual integrity of the person who is not afraid of expressing his/her own attitudes – but only those relying on thoroughly examined facts". Truth was one of the key concepts around which he built his attitude toward journalism, with a great awareness of the social context in which he wrote. That is also what he taught journalists, predicting that in the 21st century they would encounter huge pressures because of the greater need for "introducing the monopoly of own truth". Within that context, Petrović and Penezić remind us of the professor's words about "the journalists' task being to help citizens to take their own attitudes and make responsible decisions. Complete information is the condition and the beginning of democracy". The authors also state that Professor Lukač was the first to observe the breakthrough of women in Yugoslav journalism of the time, noticing that women were those who were "oriented towards an interview, a somewhat

Sergije Lukač with his friends from Mostar grammar school
Photo: Radivoje Petrović

more complex and profound form, as opposed to short and quick conversations".

Although this monograph is dedicated to the journalist and professor of journalism, it is not intended solely for journalists, because Sergije Lukač was much more than that. The whole book is permeated by the memories of numerous situations from his life, which was unusual from the very first days. Namely, the development of his character was definitely affected by the fact that his mother was Swiss, and his father a Bosnian Serb, as well as by the fact that during his childhood and growing up he was "at the crossroads of different cultures", between Sarajevo and Mostar, via Bern, Budapest, Belgrade and Zagreb. His earliest days were marked by the Second World War; he was a contemporary of the post-war proletariat dictatorship, and of the breakup of the Socialist Federal Republic of Yugoslavia. Besides journalism, sport was his great love. Apart from athletics, he also liked football and skiing, while his colleague journalist, Milan Milošević, in his memory of Sergije Lukač, says that "until very old age Lukač pursued the classical ancient virtue which connects the sound body with the sound spirit… he said that game revealed someone's personality more

Sergije Lukač with his co-workers from the first Serbian public relations agency P.R.A.
Photo: Radivoje Petrović

than anything else". Professor Rade Veljanovski emphasizes a specific feature of Lukač's work – the fact that he considered sport a social phenomenon and that his sport journalism was "at the level of sport philosophy, hence it is particularly valuable for beginners in this branch of journalism". Lukač himself believed that "a sport journalist is a reporter, a commentator, a writer of texts, the one who interviews people and thus, someone who must be skilled in all journalist genres".

In chapter five of the monograph *Sergije Lukač – Prometheus of Journalism*, the authors provide a certain pledge to journalist descendants because "Sergije Lukač was and remains a professional and human model to generations of journalists", the man who did very much to enable us to keep up with the world when it comes to technologies, communications, media and journalism on the whole. That is why the involvement of the students of journalism at the Faculty of Sport, University "Union – Nikola Tesla" in collecting the material for this monograph is practical work in research journalism and a guideline for similar projects in the future.

Guiding us, at moments with the features of fiction writing, through the life and work of Sergije Lukač, Radivoje Petrović and Slobodan Penezić skilfully combine the memories of Lukač's contemporaries, events from his private and professional life, journalist and academic engagement, life messages of the professor, along with the conclusion that "at the time when the fundamental principles of proper performance of journalist work have long been tested, and the ideals of this profession often completely suppressed to the background, this overview of Lukač's journalistic-academic manifesto can perfectly serve as a beacon and a signpost in the dark, in which a number of those who have been unfoundedly considered journalists and media have been traveling for a long time".

This monograph is not only returning to or remembering the past, but also a view of the future, a type of a signpost to young people who are just entering the world of journalism and a reminder to professional journalists of returning to the basic principles of the profession. Honour and knowledge. The manner in which the monograph was prepared may serve to man others as a motive "to return to professionalism, knowledge, truth, honesty and honour, all those characteristics endowing the personality and work of Sergije Lukač in a sea of manipulations and propaganda layers which, among other things, seriously undermine the status of a beautiful and useful profession which was formerly a responsible profession above all".

Due to the all above-mentioned, I recommend this book as literature not only to those who will go in for journalism as a profession, but to the entire readership which, by reading the monograph about Professor Sergije Lukač, will be able to understand the challenges facing today's journalism and to re-examine the expectations concerning journalists and media, i.e., the degree of own critical perception of the reality, which was frequently spoken about by Professor Lukač himself.

References

Petrović, R., Penezić, S. (2023). *Sergije Lukač – Prometheus of Journalism*. Belgrade: Faculty of Sport, University "Union – Nikola Tesla", Službeni glasnik. [In Serbian]

List of peer reviews for the journal *Progress* in 2024

Name Surname	Academic degree	Affiliation	Academic position
Bazić, Jovan	PhD	University of Priština, in Kosovska Mitrovica, Teacher Education Faculty	Full Professor
Bajić, Predrag	PhD	Union-Nikola Tesla University Faculty of Sport	Assistant Professor
Baltazarević, Borivoje	PhD	Institute for Serbian culture Priština – Leposavić	Research Fellow
Blagojević, Stevan	PhD	Institute of General and Physical Chemistry, Belgrade	Senior Research Fellow
Bogdanovski, Mašan	PhD	University of Belgrade, Faculty of Philosophy	Associate Professor
Bojković, Zoran	PhD	University of Belgrade, Faculty of Transport and Traffic Engineering	Full Professor
Vasin, Goran	PhD	University of Novi Sad, Faculty of Philosophy	Full Professor
Vasković Jovanović, Mina	PhD	University of Kragujevac, Faculty of Engineering	Associate Professor
Velički, Lazar	PhD	University of Novi Sad, Faculty of Medicine	Full Professor
Vuksanović, Divna	PhD	University of Arts in Belgrade, Faculty of Dramatic Arts	Full Professor

Vuletić, Vladimir	PhD	University of Belgrade, Faculty of Philosophy	Full Professor
Gavrilović Božović, Marijana	PhD	University of Kragujevac, Faculty of Engineering	Assistant Professor
Glišin, Vanja	PhD	Institute for Political Studies, Belgrade	Research Fellow
Gogić, Miljan	PhD	University of Montenegro, Historical Institute	Research Fellow
Despotović, Ljubiša	PhD	Institute for Political Studies, Belgrade	Principal Research Fellow
Erić, Dejan	PhD	Belgrade Banking Academy	Full Professor
Ignjatović, Dragan	PhD	University of Belgrade, Faculty of Mining and Geology	Full Professor
Jakovljević, Đorđe	PhD	Coventry University (United Kingdom – Great Britain), Research Centre for Health and Life Sciences	Full Professor
Jović, Slađana	PhD	University of Belgrade, Faculty of Security Studies	Full Professor
Jovović, Aleksandar	PhD	University of Belgrade, Faculty of Mechanical Engineering	Full Professor
Kaluđerović Radoičić, Tatjana	PhD	University of Belgrade, Faculty of Technology and Metallurgy	Full Professor
Kandić, Aleksandar	PhD	University of Belgrade, Faculty of Philosophy, Institute for Philosophy	Research Fellow
Knežević, Dinko	PhD	University of Belgrade, Faculty of Mining and Geology	Full Professor
Kolonja, Božo	PhD	University of Belgrade, Faculty of Mining and Geology	Full Professor

Kocvar, Vladimir	PhD	University of Prešov, Faculty of Orthodox Theology	Assistant Professor
Luknar, Ivana	PhD	Institute for Political Studies, Belgrade	Research Fellow
Lutovac, Svetislav	PhD	Megatrend University, Faculty of Law	Associate Professor
Lutovac, Stevan	PhD	Faculty of Management, Sremski Karlovci	Assistant Professor
Mitrović, Dragana	PhD	University of Belgrade, Faculty of Political Sciences	Full Professor
Mitrović, Ljubiša	PhD	University of Niš Faculty of Philosophy	Professor emeritus
Mladenović, Vladimir	PhD	University of Kragujevac, Faculty of Technical Sciences	Full Professor
Pantović, Radoje	PhD	University of Belgrade, Technical faculty in Bor	Full Professor
Radovanović, Snežana	PhD	University of Kragujevac, Faculty of Medical Sciences	Associate Professor
Simonović, Branislav	PhD	Institute of General and Physical Chemistry, Belgrade	Principal Research Fellow
Stanković, Vesna	PhD	University of Kragujevac, Faculty of Medical Sciences	Full Professor
Stojadinović, Miša	PhD	Institute for Political Studies, Belgrade	Principal Research Fellow
Tanasković, Irena	PhD	University of Kragujevac, Faculty of Medical Sciences	Full Professor
Tomić, Boban	PhD	Higher School of Communications, Belgrade	Associate Professor

Trailović, Dragan	PhD	Institute of International Politics and Economics, Belgrade	Research Fellow
Ćirić, Marija	PhD	University of Kragujevac, Faculty of Philology and Arts	Full Professor
Hanić, Hasan	PhD	Belgrade Banking Academy	Professor emeritus
Cvetković, Vladimir	PhD	University of Belgrade, Faculty of Security Studies	Full Professor
Šmakić, Katarina	PhD	Faculty of Diplomacy and Security, Belgrade	Assistant Professor