



## The Impact of Climate Change on the Mining Sector: A Global Perspective and Specifics in the Republic of Serbia

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### ABSTRACT

Climate change is one of the most complex challenges of the 21<sup>st</sup> century, with both direct and indirect consequences for the global economy, making the mining sector especially vulnerable. As a foundational industry, mining contributes to greenhouse gas emissions and faces significant operational risks from extreme weather events. This paper presents an analysis of global trends and the specific challenges confronting the mining sector in the Republic of Serbia. Through a review of literature and recent reports (2012-2026), the paper examines the effect of droughts, floods, and heatwaves on mining operations, tailings stability, and ecological impact. Special attention is given to the need for proactive adaptation and decarbonization strategies to ensure the sector's long-term sustainability.

### 1. Introduction

The mining sector is the foundation of modern development by supplying raw materials for infrastructure and renewable energy technologies. However, its reliance on natural conditions makes it highly vulnerable in an era of climate instability. As global attention turns to decarbonization and supply chain resilience, Serbia faces particular challenges due to outdated infrastructure and a rising frequency of extreme

precipitation and droughts (Vranić et al., 2021; Vujović et al., 2025). This paper provides an integrated overview of the impact of climate change on mining, linking global paradigms with local empirical data.

### 2. Global Climate Footprint and Mining Vulnerability

Mining is an energy-intensive industry that significantly contributes to global CO<sub>2</sub> emissions. The

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move to exploit deeper and lower-grade deposits further increases energy and water consumption (Mudd, 2012; Bellois, 2022).

### 2.1. Physical Risks

Global operations are exposed to:

- **Water Extremes:** Floods in Queensland, Australia, have demonstrated how extreme precipitation can paralyze production and threaten dam stability (United Nations Environment Programme, 2024). Conversely, droughts in Chile and Mongolia intensify conflicts over scarce water resources (Akchurin, 2025; Purevjav, 2025).
- **Heatwaves:** Rising temperatures endanger worker health and reduce productivity, while fires threaten infrastructure in arid regions.
- **Supply Chains:** Climate shocks act as a risk multiplier, destabilizing the global market for critical minerals essential to the green transition (Werner, 2024).

### 2.2. Decarbonization of the Mining Sector and Green Technologies

Global efforts to decarbonize the mining sector focus on reducing greenhouse gas emissions through innovative technologies. Key strategies include electrifying mining machinery, transitioning to renewable energy sources, and exploring hydrogen's potential as a clean fuel (IGF, 2024).

- **Electrification:** Replacing diesel-powered vehicles and equipment with electric alternatives significantly reduces direct emissions. This is especially relevant for underground mines, where it also improves air quality for workers. However, it requires substantial investment in charging infrastructure and a stable supply of electricity from clean sources.
- **Hydrogen:** Hydrogen is recognized as a promising energy carrier for decarbonizing heavy mining equipment and processes. It can be used in fuel cells to power vehicles or as a reducing agent in metallurgy, replacing coke (Lokar et al., 2025). However, producing green hydrogen remains expensive and energy-intensive, limiting its widespread application.
- **Renewable Energy Sources:** Integrating solar, wind, and geothermal energy sources directly into mining operations reduces reliance on fossil fuels and long-term operating costs. For example, Chile leads in using solar energy to power copper mines (Haas et al., 2020).

## 3. Specifics of Climate Change in Serbia

Serbia exhibits a clear warming trend. During the

period 2011-2020, the average temperature increased by 1.8 °C compared to the reference period 1961-1990, while summer maximums rose by as much as 2.6 °C (World Bank Group, 2024; Mikić et al., 2025a). These challenges are manifested through direct and indirect impacts of extreme weather events, such as droughts and floods, as well as through the exacerbation of existing environmental problems associated with mining activities (Martin, 2024).

### 3.1. Impact of Droughts and Floods on Domestic Mining

- **Water Deficit and Energy Dependency:** Mining in Serbia, particularly in the Bor and Kolubara basins, requires large quantities of water for flotation, dust suppression, and cooling. In the Kolubara basin, water is essential not only for mining operations but also for thermal power plants (e.g., TPP Nikola Tesla - TENT and TPP Kolubara A) that rely on this coal. These plants require vast amounts of water for their cooling systems to maintain energy efficiency and operational stability (Jovic, 2018). Frequent droughts reduce groundwater levels and river flows, directly threatening both the continuity of coal production and national energy security, as over 70 % of Serbia's electricity depends on coal (Vujović et al., 2026).
- **Floods and Tailings:** The catastrophic floods of May 2014 marked a critical turning point, highlighting the extreme vulnerability of Serbia's mining and energy infrastructure. Flooding of the "Tamnava-West Field" open-pit mine created a massive artificial lake containing over 187 million cubic meters of water, paralyzing coal production for months and necessitating international assistance for pumping (Polomčić et al., 2018; Vujić et al., 2020). Beyond production loss, such events pose severe risks to tailings facilities. Many older tailings dams in Serbia lack modern leachate collection systems, and extreme precipitation increases the risk of structural failure and the spillage of toxic mining waste into the environment (Nišić et al., 2018; Sakan, 2022; Ministarstvo rudarstva i energetike RS, 2024). The 2014 events demonstrated that climate-induced floods are not only local environmental hazards but also systemic risks to the country's entire energy-industrial complex.

### 3.2. Socio-economic Impacts on Mining Communities

Climate change and its consequences for the mining sector in Serbia have significant socio-economic implications, especially for local communities directly dependent on mining activities. Mining regions such as Bor and Kolubara face specific challenges (Vujović et al., 2025).

- **Worker Health and Safety:** The increased frequency of heatwaves and extreme weather conditions directly affects working conditions, raising the risk of heat stress and injuries (Taggart et al., 2024). This can reduce productivity and increase costs for occupational safety measures (Taggart et al., 2024).
- **Migration and Demographic Changes:** Permanent suspension of mine operations due to climate extremes can cause job losses and economic instability, encouraging population migration from mining regions (Nel et al., 2023). This further burdens local budgets and reduces the availability of skilled labor (Nel et al., 2023).
- **Conflicts over Resources:** Reduced water availability due to droughts can intensify conflicts between mining companies and local populations, especially in rural areas where water is used for agriculture and daily needs. These conflicts can jeopardize the "social license to operate" of mines (Mohapatra and Kirpalani, 2016).
- **Infrastructure Impact:** Extreme precipitation and floods can damage local infrastructure (roads, bridges, energy networks) crucial for mine operations and community life (Bonnafous et al., 2017). Repairs require significant financial resources, often shifting the burden to local governments (Unterberger, 2017).

#### **4. Ecological Challenges and "Green Mining"**

Climate change worsens existing ecological problems. In arid conditions, dust dispersion from tailings, open pits and similar mining sites (e.g., in Majdanpek) leads to elevated concentrations of heavy metals in the soil (Raischi et al., 2019; Dehkordi et al., 2024; Mikić et al., 2025b). The concept of "green mining," including worldwide lithium extraction, carries its own risks related to water consumption, which becomes critical under projected climate extremes (Forbes Srbija, 2025).

##### **4.1. Comparative Analysis of Regulations: EU and Serbia**

The regulatory framework plays a crucial role in shaping the mining sector's response to climate change. The European Union, through its Green Deal and ambitious climate targets, sets high standards for decarbonization and sustainable resource management. Serbia, as a candidate for EU membership, strives to harmonize its legislation with the EU acquis, including in environmental protection and climate change (Marjanović, 2025).

- **EU Regulation:** The EU focuses on reducing GHG emissions, promoting a circular economy, and ensuring that critical raw materials are

sourced sustainably. Strict regulations on Environmental Impact Assessment (EIA) and Strategic Environmental Assessment (SEA) are being introduced, as along with directives on industrial emissions and waste management. Special emphasis is placed on transparency and accountability of companies throughout the supply chain.

- **Regulation in Serbia:** Although Serbia has laws on environmental protection and impact assessment, implementation and enforcement are often challenging. The Draft Strategy for Mineral Resource Management until 2040 recognizes the need to align with EU standards, but strengthening institutional capacities and more effective application of existing regulations are necessary (Ministarstvo rudarstva i energetike RS, 2024). Current research highlights that while the legal framework is evolving, actual enforcement remains limited by institutional capacity and the complex intermingling of economic transition elements, which often hinders effective responses to climate and environmental challenges (Vujović et al., 2026).
- **Harmonization Challenges:** Harmonization with EU regulations in Serbia faces obstacles such as insufficient financial resources, lack of expert staff, and resistance to change. The complexities of projects like Jadar demonstrate the tension between geopolitical mineral demands and local socio-environmental concerns, illustrating how mining projects can become focal points for legal and political disputes over sustainability and Europeanization (Stevović and Ćircă, 2025; Vivoda, 2025).

#### **5. Adaptation and Mitigation Strategies**

For the sustainability of the sector, the following measures are necessary:

##### **5.1. Water Resource Management and Resilience to Extreme Events**

Efficient water resource management is crucial for mining operations, especially in regions affected by droughts and floods. Implementing advanced monitoring and forecasting systems for water levels, optimizing water consumption through recycling and reuse, and rainwater harvesting are fundamental adaptation measures. Constructing and maintaining adequate drainage systems and dams around mines and tailings facilities are vital for preventing floods and the spread of pollution during extreme precipitation (Loginova and Batterbury, 2019). Case studies from Australia show that mining companies have invested in sophisticated water management systems, including wastewater treatment and storage for dry periods, to ensure business continuity

and reduce their ecological footprint (Loginova and Batterbury, 2019; Firmani, 2024).

## 5.2. Reclamation, Remediation, and Biodiversity

Reclaiming degraded mining areas is an essential adaptation and mitigation measure. Biological reclamation, including afforestation and greening of tailings, contributes to soil stabilization, erosion reduction, and soil quality improvement. Selecting drought- and high-temperature-resistant plant species is crucial for the success of these projects under changing climate conditions. Remediating old and abandoned mines and landfills is also necessary to prevent further pollution and reduce the risks of landslides and toxic spills, especially during intense precipitation (Miler et al., 2022; Gaberšek et al., 2025). Examples from Bor, where tailings reclamation is underway, demonstrate the potential for reducing pollution and contributing to climate change mitigation through carbon dioxide absorption (Mikić et al., 2024a; Punia and Singh, 2025).

A prominent example is the reclamation of the RTH (Ore Body H) flotation tailings near the city of Bor. The RTH tailings facility, which has reached its final contour, represents a significantly degraded area, totaling of 551,200 m<sup>2</sup> that required urgent technical and biological intervention to mitigate environmental risks, such as dust dispersion and acid mine drainage. The reclamation model implemented at this site involves a multi-layered approach:

- **Technical Reclamation:** This phase included stabilizing the tailings surface and applying a 0.1 m thick lime filler layer to neutralize acidity, followed by a 0.5 m thick layer of humus/mold soil to provide a substrate for plant growth.
- **Biological Reclamation:** The biological phase focused on establishing a vegetation cover using specific grass-legume mixtures and planting woody species (afforestation). This process not only stabilizes the soil but also contributes to carbon sequestration, with the potential to absorb significant amounts of CO<sub>2</sub> over time (Mikić, 2024b; Mikić et al., 2025b).

The successful reclamation of the RTH tailings serves as a benchmark for other facilities in the region, such as the active Veliki Krivelj tailings dump, where continuous monitoring and auscultation are conducted to ensure structural stability and environmental safety (Lekovski et al., 2013; Nišić et al., 2018). These measures are vital for enhancing the ecological resilience of mining landscapes against the increasing frequency of climate-induced extreme weather events.

## 5.3. Energy Efficiency and Transition to Renewable Energy Sources

Reducing greenhouse gas emissions in mining is

achieved by transitioning to cleaner energy sources and increasing energy efficiency. This includes implementing renewable energy sources (solar, wind, geothermal) to power mining equipment and facilities. Many global mining companies are setting ambitious net-zero emission targets and investing in hybrid energy systems that combine renewables with energy storage (Stroykov et al., 2026). In Serbia, the potential for installing solar panels on inactive tailings and unused mining areas can contribute to decarbonizing the energy sector and reducing mine operating costs (Pavlović et al., 2021). Additionally, optimizing mineral extraction and processing, as well as introducing energy-efficient equipment, significantly contributes to reducing fossil fuel consumption and emissions.

## 5.4. Integrated Planning and International Cooperation

Successful adaptation and mitigation require integrated planning at both national and local levels. This includes incorporating climate risks into mining development strategies, spatial plans, and environmental impact assessments. Collaboration among mining companies, scientific institutions, government bodies, and local communities is essential for knowledge exchange, developing innovative solutions, and effectively implementing measures. Implementing adaptation and mitigation measures helps create a more resilient and sustainable mining sector in Serbia (Mikić et al., 2025a). International cooperation, through the exchange of best practices and financial support, can accelerate the transition to climate-resilient mining, especially in developing countries most vulnerable to climate change (Vranić et al., 2021; Solomun et al., 2025).

## 6. Conclusion

The mining sector in Serbia and globally is at a crossroads. While global trends call for rapid decarbonization, local challenges in Serbia require urgent remediation of inherited ecological problems and adaptation of infrastructure to potential extreme climatic conditions. Only by integrating scientific knowledge, modern technologies, and strict regulations can mining continue to drive development without compromising the ecological security of future generations.

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## Uticaj klimatskih promena na rudarski sektor: Globalna perspektiva i specifičnosti u Republici Srbiji

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### I Z V O D

Klimatske promene predstavljaju jedan od najsloženijih izazova 21. veka, sa direktnim i indirektnim posledicama po globalnu ekonomiju, pri čemu je rudarski sektor naročito izložen njihovim uticajima. Kao jedna od osnovnih industrijskih grana, rudarstvo doprinosi emisiji gasova sa efektom staklene bašte, ali je istovremeno suočeno sa značajnim operativnim rizicima usled ekstremnih vremenskih pojava. U radu je prikazana analiza globalnih trendova i specifičnih izazova sa kojima se suočava rudarski sektor u Republici Srbiji. Na osnovu pregleda relevantne literature i savremenih izveštaja (2012-2026), razmatra se uticaj suša, poplava i toplotnih talasa na rudarske aktivnosti, stabilnost jalovišta i ekološke posledice eksploatacije mineralnih sirovina. Posebna pažnja posvećena je potrebi za proaktivnim strategijama prilagođavanja i dekarbonizacije radi obezbeđenja dugoročne održivosti sektora.