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THE IMPACT OF CLIMATE CHANGE ON MINING IN SERBIA, AN OVERVIEW

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Abstract
This paper aims to analyze the impact of climate change on the mining sector in Serbia, with a particular focus on the consequences of droughts and floods, as well as broader ecological implications. Through a review of existing data and research, the key challenges facing mining will be presented, as well as potential adaptation and mitigation measures that can contribute to reducing the sector's vulnerability to climate change.

***Keywords**: climate change, mining, ecology.*

1. INTRODUCTION

Climate change represents one of the greatest global challenges of the 21st century, with far-reaching consequences for all sectors of the economy and society. The Republic of Serbia, as a country located in a region particularly vulnerable to climate change, is facing increasingly pronounced extreme weather events. In recent decades, a significant increase in average temperatures, an increased frequency of heatwaves, and changes in precipitation patterns resulting in more frequent droughts and more intense floods have been recorded. These changes directly affect natural resources and ecosystems, as well as key economic sectors, including mining.

Mining in Serbia has a long tradition and represents an important segment of the national economy, contributing to the gross domestic product and employment. However, mining activities are inherently associated with significant environmental impacts, including air, water, and soil pollution, as well as landscape degradation. In the context of climate change, these impacts become even more complex, as climate extremes can exacerbate existing risks and create new challenges for the sustainability of the mining sector. Understanding and adapting to these changes are crucial for minimizing negative consequences and ensuring the long-term sustainability of mining in Serbia.

2. CLIMATE CHANGE IN SERBIA: AN OVERVIEW

The Republic of Serbia is facing significant climate changes that are manifested through multiple aspects. Analyses of climate data for the period 2001–2020, compared to the reference period 1961–1990, show a clear warming trend. The average surface air temperature in Serbia has increased by 1.4 °C, while in the more recent period (2011–2020), this increase is even more pronounced, reaching 1.8 °C. Particularly concerning is the increase in the average maximum temperature during the summer months (June-July-August), which in the period 2011–2020 reached as much as 2.6 °C compared to the reference period. Projections indicate a continuation

of this trend, with an expected temperature increase of about 2.2 °C by 2040, 3.1 °C by 2060, and according to the RCP8.5 scenario, even 5.8 °C by the end of the century (2100).

Parallel to the temperature increase, Serbia is also experiencing an increased frequency and intensity of heatwaves. In the period 2011–2020, the average number of heatwaves per year increased by three compared to the reference period. It is predicted that by 2040, there will be 4-5 more heatwaves annually, while by the end of the century, according to the RCP8.5 scenario, the average number of heatwaves could reach 8-10 annually, which would mean about two months of extremely hot weather. These changes have a direct impact on human health, agriculture, water resources, and energy.

Regarding precipitation, changes in its regime have been observed, although annual precipitation sums do not show significant changes. However, a decrease in precipitation during the summer months (JJA season) was recorded, with an 8% drop in the period 2011–2020 compared to the reference period. At the same time, the frequency and intensity of extreme precipitation have increased, leading to more frequent and devastating floods. Droughts, as a consequence of reduced summer precipitation and rising temperatures, are becoming increasingly pronounced, threatening water resources, river flows, and groundwater. These climate changes create complex challenges for all sectors, including mining, which is particularly sensitive to changes in water availability and extreme weather events.

3. THE IMPACT OF CLIMATE CHANGE ON THE MINING SECTOR IN SERBIA

The mining sector in Serbia, although vital to the economy, faces significant challenges due to climate change. 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[1].

Droughts and Water Scarcity

Mining is an industry that requires significant amounts of water for various processes, including ore processing, equipment cooling, and dust suppression. Increasingly frequent and intense droughts in Serbia directly threaten the availability of water resources necessary for mining operations. Water scarcity can lead to reduced production capacities, increased operating costs, and even temporary mine closures. In addition, droughts affect groundwater levels and river flows, further complicating water supply for mines and surrounding communities. Studies show that prolonged droughts also affect hydropower capacities, which can indirectly impact mining, an energy-intensive industry that relies on a stable electricity supply.

Floods and Their Consequences

On the other hand, the increased frequency of extreme precipitation and floods poses a serious threat to mining facilities. Open-pit mines are particularly vulnerable to floods, which can lead to the inundation of the entire pit, production interruptions, and significant material damage [2]. Examples from 2014, when floods hit Serbia, showed that mine tailings were affected, with thousands of tons of mining waste spilling into the environment. This not only represents an ecological catastrophe but also causes long-term pollution of soil and watercourses. Floods can also damage mine infrastructure, including roads, bridges, and energy systems, further hindering recovery and resumption of operations [3].

Broader Environmental Impacts and Climate Change

The mining sector in Serbia is recognized as one of the largest polluters of air, water, and soil. Mineral extraction generates huge amounts of waste, pollutes natural habitats, and releases toxic substances into the environment [4,5]. Climate change exacerbates these negative impacts. For example, in conditions without wind or with reduced precipitation, pollutants from mines remain

in the atmosphere longer, worsening air quality. Increased soil erosion due to extreme precipitation can lead to the spread of pollution from tailings. Even so-called 'green mining,' such as lithium extraction, carries significant environmental risks, including high water consumption and the use of toxic chemicals, which is particularly problematic in the context of increasingly severe droughts. The increase in extreme weather events due to climate change makes mining operations inherently riskier, requiring comprehensive adaptation and mitigation measures.

Adaptation and Mitigation Measures in the Serbian Mining Sector

Addressing the challenges posed by climate change in the Serbian mining sector requires a comprehensive approach that includes adaptation and mitigation measures. Adaptation refers to adjusting existing mining operations and infrastructure to unavoidable climate changes, while mitigation involves reducing greenhouse gas emissions and minimizing the environmental footprint of mining.

Water Resource Management

Given the increasing frequency of droughts and floods, efficient water resource management becomes imperative. This includes implementing advanced monitoring and forecasting systems for water levels, optimizing water consumption in mining processes through recycling and reuse, and rainwater harvesting. The construction and maintenance of adequate drainage systems and dams around mines and tailings facilities are crucial for preventing flooding and the spread of pollution during extreme precipitation. Also, considering alternative water sources and wastewater treatment technologies can significantly reduce the vulnerability of mines to water scarcity.

Reclamation and Remediation

Reclamation of degraded mining areas is an important adaptation and mitigation measure. Biological reclamation, which includes afforestation and greening of tailings, contributes to soil stabilization, erosion reduction, and soil quality improvement. The selection of plant species resistant to drought and high temperatures is crucial for the success of these projects in changing climate conditions. Remediation of old and abandoned mines and landfills is also necessary to prevent further pollution and reduce the risks of landslides and spills of toxic substances, especially during intense precipitation [6]. Examples of tailings reclamation in Bor show the potential for reducing pollution and contributing to the fight against climate change through carbon dioxide absorption.

Emission Reduction and Energy Efficiency

Mitigation measures in mining include reducing greenhouse gas emissions. This can be achieved through transitioning to cleaner energy sources, such as renewable energy (solar, wind), to power mining equipment and facilities. Increasing energy efficiency in all phases of the mining process, from extraction to processing, also contributes to reducing fossil fuel consumption and emissions. The implementation of new technologies that reduce dust and harmful gas emissions, as well as improving air ventilation and filtration systems, directly impact air quality and reduce health risks for workers and local communities.

Integrated Planning and Cooperation

Successful adaptation and mitigation require integrated planning at national and local levels. This involves incorporating climate risks into mining development strategies, spatial plans, and environmental impact assessments. Cooperation among mining companies, scientific institutions, government bodies, and local communities is crucial for knowledge exchange, developing innovative solutions, and effective implementation of measures. Raising awareness about the importance of climate change and its impact on mining, as well as educating workers and the public, contributes to creating a more resilient and sustainable mining sector in Serbia.

4. CONCLUSION

Climate change poses an increasing challenge for the mining sector in Serbia, bringing with it risks from extreme weather events such as droughts and floods, which directly threaten mining operations and infrastructure. In addition, climate extremes exacerbate existing environmental problems related to mining, such as water, air, and soil pollution. Rising temperatures and changes in precipitation patterns require an urgent and comprehensive response to ensure the sustainability of this vital economic sector.

Successful adaptation and mitigation in the Serbian mining sector involve implementing a range of measures, including efficient water resource management, reclamation and remediation of degraded areas, reduction of greenhouse gas emissions, and increased energy efficiency. Integrated planning, cooperation among all relevant stakeholders, and raising awareness about the importance of climate change are also crucial. Only through a proactive approach and the application of sustainable practices can the Serbian mining sector become more resilient to future climate challenges and contribute to broader efforts for environmental protection and achieving climate neutrality.

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