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POTENTIAL AND GEOTECHNICAL CHALLENGES OF IMPLEMENTING PHOTOVOLTAIC POWER PLANTS ON FLOTATION TAILINGS AND WASTE DUMPS OF OPEN PITS IN THE BOR DISTRICT

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Abstract

This paper explores the integration of photovoltaic power plants on passivated flotation tailings and open pit waste dumps across the Bor District copper mining complex. Mining operations have created extensive degraded land, presenting environmental risks such as erosion and dust emissions. Installing solar energy systems on these post-industrial sites supports the "Green Mine" paradigm, offering dual benefits: ecological restoration of degraded land without consuming agricultural resources, and decentralized clean energy generation directly at high-consumption industrial nodes. Geotechnical challenges, including terrain settlement, low bearing capacity, and corrosive environments, require specialized engineering solutions like concrete ballast systems and flexible racking.

***Keywords**: Green Mine, flotation tailing, solar energy systems, ecological restoration*

1. INTRODUCTION

Modern mining stands at a critical juncture defined by the imperative to decarbonize industrial processes and adopt the principles of a circular economy [1-4]. The extraction and processing of copper ores in the Bor District (conducted by companies Serbia Zijin Copper and Serbia Zijin Mining) are accompanied by the generation of vast degraded land areas—primarily open pit waste dumps and flotation tailings ponds [1,2]. These sites pose a significant environmental challenge regarding structural stability, erosion, and fugitive dust emissions [2].

Conversely, the transition toward the "Green Mine" concept requires identifying suitable locations for installing renewable energy sources (RES) [4]. Constructing photovoltaic power plants (PVPP) on passivated or progressively closed sections of mining waste dumps offers a dual benefit [1,5]:

1. Environmental and Functional: Utilizing already degraded land preserves valuable agricultural and forestry resources [5].

2. Energy Efficiency: Generating electricity directly at high-consumption sites (flotation plants, smelters, underground mining operations) reduces grid load and directly lowers the carbon footprint of mining operations [3,4].

The objective of this paper is to analyze the technical feasibility, geotechnical challenges, and capacity potential for installing photovoltaic systems at selected copper mining locations in the Bor District.

2. GEOTECHNICAL AND ENGINEERING CHALLENGES OF PANEL MOUNTING ON MINING WASTE

Unlike standard terrain, open-pit overburden dumps and flotation tailings ponds are characterized by unique geomechanical and physicochemical properties that directly influence the selection of solar panel mounting structures [1,2]:

a) Terrain Settlement and Bearing Capacity

- **Open pit Waste Dumps:** Composed of uncompacted rock material with variable grain-size distribution, these dumps experience long-term secondary settlement under their self-weight and atmospheric precipitation [2].
- **Flotation Tailings Ponds:** Consisting of fine-grained, often saturated material with low bearing capacity, these areas carry risks of consolidation or liquefaction under elevated moisture conditions [2].

b) Engineering Solutions for Support Structures

Due to the impracticability of conventional shallow foundations, the following methods are deployed [2,5]:

- **Concrete Ballast Systems:** Provide surface loading without deep excavation, ideal for stabilized tailings ponds where penetrating the impermeable layer or capping membrane must be avoided.
- **Piling:** Applicable to rock waste dumps subject to prior geotechnical verification of rock block depth and stability.
- **Flexible/Adjustable Mounting Systems:** Frameworks that allow post-installation re-leveling of panels in response to uneven ground settlement.

c) Environmental Exposure and Equipment Protection

The presence of heavy metals, dust, and Acid Mine Drainage (AMD) requires the application of anti-corrosive protective coatings on metal supports, as well as the selection of PV modules with high IP ratings for dust and environmental protection [2,4].

3. ANALYSIS OF POTENTIAL LOCATIONS IN THE BOR DISTRICT

Given the diversity of mining facilities across the Bor Basin, photovoltaic systems can be strategically deployed across several characteristic locations, table 1 [1].

Table 1. *Overview of Locations and Estimated Capacities*

Location / Facility	Type of Degraded Terrain	Available Area (ha)*	Expected Installed Capacity (MWp)**
Flotation Tailings Veliki Krivelj (Polje 1, 2, and Nulto)	Passivated surfaces / Dam crest	690	483.0
Flotation Tailings RTH	Passivated surfaces / Dam crest	85	59.5
Čukaru Peki Site	Industrial zone / Waste dumps	108	75.6
Majdanpek (Valja Fundata)	Passivated surfaces / Dam crest	452	316.4
Open pit Veliki Krivelj and Sarak Potok waste dump	Waste dumps/open pit	700	490

**Estimated surface areas.*
***Calculated using an average coefficient of 0.7 MWp per hectare (typical installation yields range from 0.6 to 0.8 MWp/ha depending on tilt angle and panel type).*

4. TECHNICAL, ENERGY, AND ENVIRONMENTAL IMPACT ANALYSIS

Deploying photovoltaic systems on degraded land across the Bor Basin yields direct positive impacts across three main domains:

a) Energy Balance and Decentralization

On-site electricity generation at major demand nodes (flotation units, mine dewatering pumping systems, industrial processing facilities) significantly reduces load on the regional transmission grid and minimizes transmission losses [3]. Given the average solar irradiance in the Bor District (approx. 1200 – 1300 kWh/annually), the installed capacity delivers a stable energy yield during peak spring and summer months.

b) Environmental Benefits and Microclimate

- **Surface Stabilization:** Panel arrays act as a physical barrier against wind action, suppressing wind erosion and fugitive dust transport toward nearby communities (Bor, Krivelj, Oštrelj) [1,2].
- **Water Conservation:** Shading provided by the arrays reduces surface evaporation, facilitating vegetation establishment in areas designated for combined bio-technical land reclamation [1].
- **Carbon Footprint Reduction:** Every megawatt-hour (MWh) produced from solar power in Serbia avoids approximately 0.8 - 0.9 tonnes of CO_2 emissions compared to lignite-based power generation [3].

c) Economic and Regulatory Aspects

Repurposing degraded mining land eliminates land acquisition or leasing costs associated with agricultural or commercial real estate [5]. Furthermore, it enhances corporate Environmental, Social, and Governance (ESG) performance, which is increasingly critical for marketing copper and gold in global markets [4].

5. DISCUSSION AND IMPLEMENTATION RECOMMENDATIONS

Considering the specific operational context of Serbia Zijin Copper and Serbia Zijin Mining, project execution should follow a phased approach [4]:

1. **Geotechnical Consolidation Phase:** Selecting sites that have been inactive for at least 3 to 5 years to ensure primary material settlement is complete.
2. **Subgrade Preparation Phase:** Regrading terrain and installing an isolating/stabilizing layer (e.g., clay layer or geomembrane combined with gravel) to prevent contact with acidic drainage.
3. **Equipment Selection Phase:** Utilizing heavy-duty industrial inverters and solar panels with high corrosion resistance against airborne particulates and sulfur compounds.
4. **Hybrid Reclamation Model:** Integrating solar arrays with shallow-rooted native vegetation planted between panel rows (bio-solar or agrivoltaic concept) [1].

6. CONCLUSION

Converting passivated tailings ponds and overburden waste dumps in the Bor District into photovoltaic power plants offers a highly sustainable pathway for addressing two major challenges of modern mining: land rehabilitation and energy decarbonization [1, 4, 5].

While geotechnical conditions on mining waste require rigorous planning and specialized engineering solutions—such as flexible racking and ballast systems—the technical, environmental, and economic justifications are compelling [2, 5]. Leveraging the extensive land assets of the mining complexes in Bor and Majdanpek can position the region as a benchmark for green transition in the mining sector [4].

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