



INTEGRATED STRATEGIES FOR MINING WASTE VALORIZATION TO IMPROVE RESOURCE EFFICIENCY

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Abstract: Mining regions undergoing economic transition face significant challenges related to the management of waste generated by extractive activities. In the Jiu Valley, waste rock dumps associated with coal mining represent substantial accumulations of residual materials that may cause environmental impacts but can also be considered valuable secondary resources. The Vulcan area represents a relevant case study for assessing the potential reuse of mining waste within the context of resource efficiency improvement. This paper proposes an integrated strategy for the valorization of mining waste from the existing dumps in the Vulcan area, aiming to transform these materials from waste into useful resources. Mining waste, predominantly composed of sedimentary rocks associated with coal seams, can be processed through sorting, crushing, and granulometric classification in order to be used in infrastructure works, embankments, or for stabilizing land affected by mining activities. The implementation of this strategy contributes to reducing the volume of deposited materials and decreasing the demand for natural aggregates extracted from other sources. At the same time, the valorization of mining waste can support the economic regeneration of mining regions in the Jiu Valley by promoting efficient resource use and the application of circular economy principles within the extractive sector.

Keywords: Mining waste; Resource efficiency; Circular economy; Waste valorisation; Jiu Valley; Mine waste dumps

1. Introduction

Mining regions undergoing economic transition and industrial restructuring face multiple challenges related to the long-term environmental impact generated by extractive activities. One of the most significant issues is represented by the large accumulations of mining waste produced during resource exploitation, which occupy extensive areas and may generate negative effects on environmental components. At the same time, within the current context of sustainable development and the transition toward a circular economy, these residual materials are increasingly being reconsidered as secondary resources with significant valorization potential. [1, 2, 3]

The Jiu Valley represents one of the most important mining regions in Romania, where coal exploitation contributed for decades to the economic and social development of the area. However, the gradual reduction of mining activities and the closure of mining operations have generated numerous environmental and economic problems, among which the existence of waste rock dumps resulting from coal extraction and processing activities is particularly significant. These deposits contain considerable quantities of mineral materials, mainly sedimentary rocks associated with coal seams, which were long considered simple waste materials without economic value.

In recent years, the concept of mining waste valorization has become an important component of strategies aimed at improving resource efficiency and reducing environmental impact. Through the application of

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circular economy principles, materials generated by mining activities can be reintegrated into the economic cycle, contributing to the reduction of natural resource consumption and the decrease in the volume of deposited waste. In this context, mining waste dumps can become alternative sources of raw materials for various applications in construction, infrastructure development, and land stabilization works in mining-affected areas.

The Vulcan area provides a relevant case for analyzing the possibilities of mining waste reuse in order to improve resource efficiency. The existence of extensive waste dumps, predominantly composed of materials with favorable granulometric and mechanical properties, creates the premises for the development of integrated valorization solutions. Through processes such as sorting, crushing, and granulometric classification, these materials can be transformed into aggregates suitable for infrastructure works, embankments, filling materials, or land rehabilitation projects.

The implementation of integrated mining waste valorization strategies can generate multiple benefits from both economic and environmental perspectives. Reducing the quantities of deposited materials contributes to limiting the risks associated with dump instability and to decreasing the impact on soil, water, and landscape quality. At the same time, the reuse of these materials reduces the need for extracting natural aggregates from other sources, contributing to resource conservation and lowering environmental pressure.

Furthermore, the development of mining waste valorization activities may support the economic regeneration process of mining communities in the Jiu Valley. The creation of economic flows based on the reuse of existing resources can generate opportunities for the development of complementary industrial activities and for the creation of jobs in sectors associated with the circular economy and sustainable resource management. [4, 5, 6]

The present paper proposes an integrated approach regarding the valorization of mining waste existing in the Vulcan area, aiming to identify sustainable solutions for transforming these materials from environmental liabilities into useful resources. The study highlights the technical and economic potential of mining waste reuse and emphasizes the importance of implementing strategies focused on resource efficiency and the sustainable development of mining regions undergoing economic transition. [7, 8]

2. Materials and Methods

The study was conducted in the Vulcan area, located in the central-western part of the Jiu Valley (Romania), a region characterized by extensive coal mining activities and the presence of significant waste rock dumps generated during decades of underground coal extraction and processing. The investigated dumps consist predominantly of sedimentary rocks associated with coal-bearing formations, including sandstones, claystones, siltstones, and shale fragments.

Field investigations were carried out between March 2024 and August 2025 and included site inspections, geomorphological observations, mapping activities, sample collection, and laboratory analyses. Five representative investigation points were selected within the main waste disposal areas, namely the Vulcan Main Dump, Coroești Dump, and secondary deposits associated with former mining operations. The sampling locations were selected based on material heterogeneity, weathering conditions, accessibility, and potential suitability for reuse applications.

A total of 25 representative samples were collected from the investigated waste dumps. At each investigation point, five subsamples were obtained from different positions and depths ranging between 0.3 and 1.5 m below the surface. The collected subsamples were homogenized to obtain composite samples representative of each analyzed sector. Sampling activities were performed according to SR EN 932-1 standards for aggregate sampling. The collected materials were stored in labelled containers and transported to the laboratory for further analyses.

Prior to laboratory testing, the samples were air-dried under controlled conditions, manually disaggregated, and prepared using quartering procedures to ensure representative material characterization. The processed samples were subsequently divided into fractions designated for physical-mechanical and chemical analyses.

Granulometric characterization of the materials was performed through mechanical sieving using standardized sieves according to SR EN 933-1. The analyses focused on determining particle size distribution and identifying material categories with potential reuse applications in infrastructure works. The results highlighted the predominance of fine and medium fractions (0–4 mm and 4–20 mm), which are characteristic of mining waste generated from sedimentary rocks associated with coal seams.

In order to evaluate the mechanical properties of the materials, tests regarding crushing resistance and compaction behavior were carried out. Resistance to wear and fragmentation was determined using the Los Angeles (LA) coefficient according to SR EN 1097-2, a method commonly applied in the assessment of aggregates intended for road construction. In addition, optimum moisture content and bulk density were analyzed to estimate the behavior of the materials in embankment and filling applications.

Chemical analyses aimed to evaluate the compatibility of the materials with the proposed reuse applications and to identify potential environmental risks associated with their valorization. Concentrations of metallic elements commonly associated with mining activities, including iron (Fe), manganese (Mn), lead (Pb), zinc (Zn), and copper (Cu), were determined after acid digestion using Atomic Absorption Spectrometry (AAS). The obtained values were compared with the reference thresholds established by Romanian environmental legislation (Order 756/1997) and with the technical requirements applicable to aggregates used in infrastructure works.

To assess the contribution of mining waste reuse to resource efficiency, a Resource Efficiency Index (E_{res}) was calculated according to Equation (1):

$$E_{res} = \frac{V_{wm}}{V_{tot}} \times 100 \quad (1)$$

Where V_{wm} represents the volume of reused mining waste, and V_{tot} represents the total volume of material required for the analyzed infrastructure works.

The Resource Efficiency Index expresses the percentage of total material demand that can be covered through the utilization of processed mining waste. Higher values indicate a greater substitution of conventional natural aggregates and a higher contribution to circular economy objectives through resource conservation and waste reduction.

The interpretation of the results was performed by correlating the physical-mechanical and chemical properties of the materials with the technical requirements specific to the proposed applications, including road infrastructure works, stabilization of mining-affected land, and industrial developments. The adopted methodology provides an integrated framework for evaluating the valorization potential of mining waste and for formulating sustainable solutions aimed at reducing natural resource consumption and minimizing environmental impact.

3. Results and Discussion

The physical and mechanical characterization of the mining waste materials collected from the Vulcan waste dumps highlighted significant variations depending on the sampling location and the degree of material weathering. Granulometric analyses indicated the predominance of fine and medium particle fractions, particularly in areas affected by long-term exposure to atmospheric conditions and mechanical fragmentation processes. The 0–4 mm and 4–20 mm fractions represented the largest proportion of the analyzed samples, suggesting favorable characteristics for potential reuse in embankments, filling materials, and road infrastructure applications.

The obtained results also revealed relatively good mechanical stability of the materials. The Los Angeles coefficient values ranged between 25% and 35%, remaining below the maximum threshold generally accepted for aggregates used in road construction works. In addition, the analyzed samples showed moderate optimum moisture content values and satisfactory compaction behavior, indicating the feasibility of using processed mining waste as substitute material for natural aggregates.

Table 1. Physical and mechanical properties of mining waste materials

Sampling Area	Dominant Fraction	LA Coefficient (%)	Optimum Moisture (%)	Bulk Density (kg/m ³)	Sampling Area
Vulcan Main Dump	0–20 mm	28	9.5	1850	Vulcan Main Dump
Coroești Dump	4–20 mm	31	10.2	1790	Coroești Dump
Secondary Dump 1	0–4 mm	35	11.4	1710	Secondary Dump 1
Secondary Dump 2	0–20 mm	27	8.7	1880	Secondary Dump 2
Control Material	Natural aggregate	22	7.9	1920	Control Material

The chemical analyses demonstrated that the investigated mining waste materials contain elevated concentrations of iron and manganese, which are characteristic of sedimentary formations associated with coal deposits. However, the concentrations of potentially hazardous metals such as lead, zinc, and copper remained below the intervention thresholds established by Romanian environmental legislation for industrial land use. These findings indicate that, following appropriate processing and selection, the analyzed materials may be suitable for controlled reuse applications without generating significant environmental risks.

Table 2. Heavy metal concentrations in mining waste materials (mg/kg)

Sampling Area	Fe	Mn	Pb	Zn	Cu
Vulcan Main Dump	31500	870	62	145	58
Coroești Dump	29800	810	55	132	51
Secondary Dump 1	28700	760	49	118	45
Secondary Dump 2	30100	790	53	125	47
Control Material	20500	480	24	68	28

The results obtained in the present study are consistent with findings reported in international research focused on mining waste valorization and resource efficiency improvement within former mining regions.

Previous studies have demonstrated that waste rock generated during coal mining operations may represent a valuable secondary resource when appropriate processing and quality control measures are applied. [3], reported that mining waste materials characterized by suitable granulometric distributions can successfully be reused in road embankments, filling applications, and infrastructure projects, reducing the dependence on natural aggregate extraction.

The mechanical properties identified in the Vulcan waste dumps are comparable with those reported for recycled mineral aggregates used in secondary road construction projects. The Los Angeles coefficient values ranging between 25% and 35% indicate satisfactory resistance to fragmentation and remain within the limits generally accepted for controlled engineering applications. Similar values have been reported by Lottermoser [9], who highlighted the technical feasibility of incorporating processed mining waste into construction materials and infrastructure developments.

The chemical analyses also support the potential reuse of the investigated materials. Although elevated concentrations of iron and manganese were identified, the concentrations of lead, zinc, and copper remained below the intervention thresholds established by Romanian environmental legislation. Comparable results have been reported in studies performed in post-mining regions from Poland, Germany, and the Czech Republic, where mining waste materials have been successfully integrated into rehabilitation projects and transport infrastructure developments without generating significant environmental risks.

The estimated Resource Efficiency Index demonstrates that mining waste materials from the Vulcan area could replace between 45% and 60% of the aggregates required for local infrastructure projects. This substitution potential is similar to values reported in European circular economy initiatives focused on the reuse of extractive waste and confirms the significant contribution that mining waste valorization can bring to resource conservation strategies.

Compared with other former coal mining regions, the Vulcan area presents several advantages, including the large volume of available waste material, the proximity of potential infrastructure projects, and the increasing policy support for circular economy implementation within the framework of the European Green Deal and the Just Transition Mechanism. These factors create favorable conditions for transforming historical mining liabilities into valuable secondary resources capable of supporting sustainable regional development.

The comparative analysis between mining waste materials and the control samples emphasizes the anthropogenic influence associated with coal extraction and waste deposition activities. Nevertheless, the absence of critical exceedances for the analyzed metals suggests that the investigated materials can be integrated into infrastructure projects under controlled conditions and in compliance with environmental regulations.

The estimated resource substitution index revealed that processed mining waste could replace approximately 45–60% of the natural aggregates required for local infrastructure works, depending on the technical specifications of the proposed applications. This substitution potential highlights the significant contribution that mining waste valorization can bring to resource efficiency and to reducing the exploitation pressure on conventional aggregate quarries.

From an environmental perspective, the reuse of mining waste materials may contribute to reducing the volume of deposited waste, limiting landscape degradation, and decreasing the risks associated with slope

instability and erosion processes within the waste dumps. At the same time, the implementation of integrated valorization strategies could support the economic regeneration of mining regions in the Jiu Valley by creating opportunities for secondary raw material utilization and the development of circular economy practices within the extractive sector.

Overall, the obtained results demonstrate that the mining waste deposits from the Vulcan area represent not only an environmental challenge, but also a potentially valuable resource that can be incorporated into sustainable infrastructure and land rehabilitation projects through appropriate processing and environmental management practices.

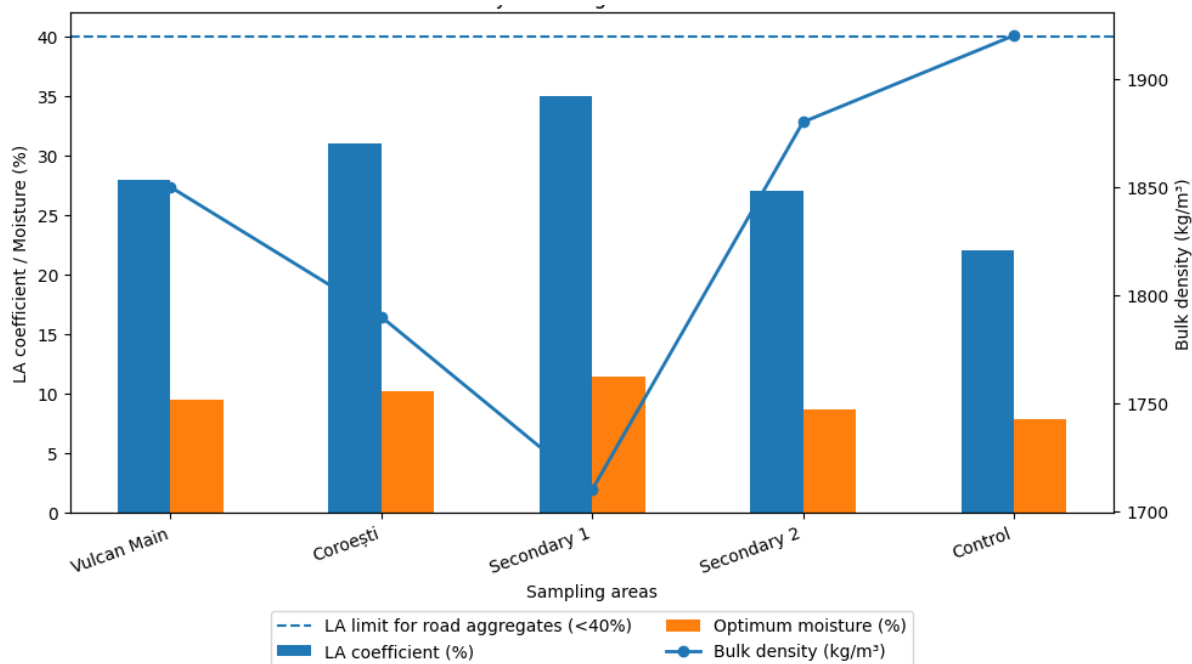


Fig. 1. Technical suitability of mining waste materials for reuse

Figure 1 highlights the mechanical behavior of mining waste materials by comparing the Los Angeles coefficient, optimum moisture content, and bulk density. All analyzed samples remain below the 40% LA threshold, indicating their potential suitability for controlled reuse in embankments, filling layers, and road infrastructure works.

Figure 2 illustrates the relative distribution of heavy metals across the investigated mining waste samples. Higher values are observed in the Vulcan Main Dump, while the control material shows consistently lower concentrations, supporting the distinction between mining-affected materials and reference material.

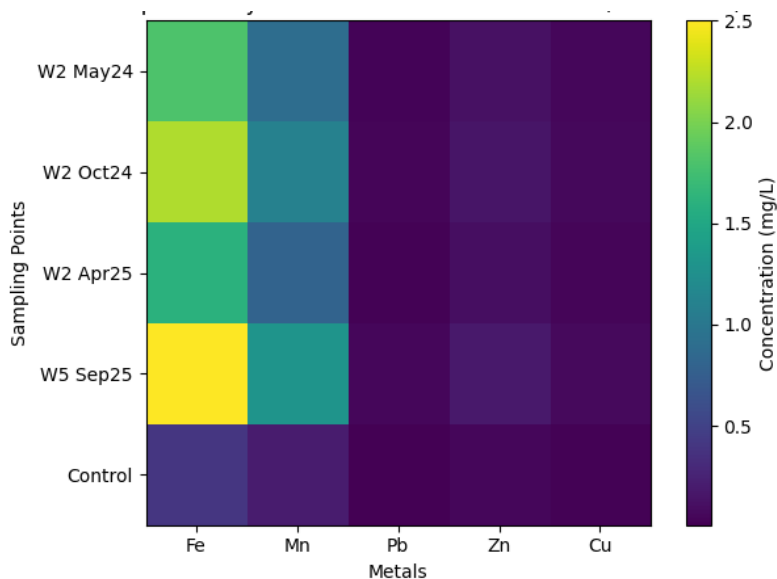


Fig. 2. Normalized heavy metal distribution in mining waste materials

3.1 Practical Implementation Framework for Mining Waste Valorization

The successful valorization of mining waste requires the integration of technical, environmental and economic measures within a structured implementation framework. Based on the results obtained in the Vulcan area, a four-stage approach is proposed for transforming mining waste deposits into usable secondary resources.

The first stage involves detailed inventory and characterization activities. This includes topographic mapping of waste dumps, estimation of available material volumes, assessment of material composition and identification of sectors presenting the highest valorization potential. Accurate characterization represents a prerequisite for ensuring the suitability of mining waste for specific engineering applications.

The second stage consists of material extraction and processing. Mining waste is selectively excavated and subjected to crushing, screening and granulometric classification processes. Depending on local conditions, mobile crushing and screening equipment may be deployed directly within the waste dump area in order to reduce transportation costs and increase operational efficiency. During this phase, unsuitable materials are separated while reusable fractions are prepared for further utilization.

The third stage focuses on quality control and application-oriented material classification. Processed materials are tested to verify compliance with the technical requirements applicable to road construction, embankments, filling layers and land rehabilitation projects. Particular attention must be paid to mechanical resistance, compaction characteristics and environmental compatibility.

The fourth stage involves the integration of processed mining waste into local infrastructure and rehabilitation projects. Potential applications include road foundations, embankments, industrial platforms, drainage systems and stabilization work in mining-affected areas. The use of processed mining waste in such projects contributes to reducing the demand for natural aggregates and supports circular economy objectives through resource conservation.

To ensure long-term sustainability, periodic monitoring should be implemented to evaluate material performance, environmental impacts and the overall effectiveness of the valorization strategy. Key performance indicators may include the quantity of mining waste reused, the reduction in waste dump volumes, the percentage of substituted natural aggregates and the environmental benefits associated with reduced extraction activities.

The proposed framework demonstrates how historical mining waste deposits can be transformed from environmental liabilities into valuable secondary resources capable of supporting sustainable infrastructure development and regional economic transition within former coal mining areas such as the Jiu Valley.

4. Conclusions

The present study demonstrates that mining waste deposits from the Vulcan area represent not only an environmental challenge resulting from historical coal mining activities, but also a valuable source of secondary raw materials that can contribute to improving resource efficiency and supporting circular economy objectives.

The physical-mechanical characterization of the investigated materials revealed favorable granulometric properties, satisfactory compaction behavior, and Los Angeles coefficient values ranging between 25% and 35%, indicating their suitability for controlled engineering applications. Chemical analyses showed that the concentrations of the investigated heavy metals remained below the intervention thresholds established by Romanian environmental legislation, supporting the feasibility of their reuse under appropriate environmental management conditions.

The calculated Resource Efficiency Index indicated that processed mining waste could potentially replace between 45% and 60% of the natural aggregates required for local infrastructure projects. This substitution potential highlights the significant contribution that mining waste valorization can make to reducing the exploitation of primary raw materials and minimizing the environmental footprint associated with aggregate extraction activities.

Beyond the technical feasibility demonstrated by laboratory analyses, the study proposes a practical implementation framework based on inventory and characterization, material processing, quality control, and integration into infrastructure projects. This approach provides a realistic pathway for transforming historical mining waste deposits into useful resources capable of supporting sustainable regional development.

From a broader perspective, the valorization of mining waste may contribute to the economic transition of former coal mining regions such as the Jiu Valley by creating opportunities for resource recovery, circular economy development, and environmental rehabilitation.

The proposed strategy is consistent with the objectives of the European Green Deal, the Circular Economy Action Plan, and the Just Transition Mechanism, highlighting the role those secondary raw materials can play in supporting sustainable development in post-mining regions.

Future research should focus on large-scale pilot applications, long-term environmental monitoring, and detailed economic assessments in order to further validate the technical and financial viability of mining waste reuse within infrastructure and land rehabilitation projects.

References

- [1] **Lottermoser B.G.**, 2010
Mine Wastes: Characterization, Treatment and Environmental Impacts, Springer, ISBN: 978-3-642-12418-1, DOI: 10.1007/978-3-642-12419-8
- [2] **Younger P.L., Banwart S.A., Hedin R.S.**, 2002
Mine Water: Hydrology, Pollution, Remediation, Springer, ISBN: 978-94-010-0617-7, DOI: 10.1007/978-94-010-0617-7
- [3] **Bian Z., Miao X., Lei S., Chen S., Wang W., Struthers S.**, 2012
The challenges of reusing mining and mineral-processing wastes, Science, ISSN: 0036-8075, DOI: 10.1126/science.1217501
- [4] **Franks D.M., Boger D.V., Côté C.M., Mulligan D.R.**, 2011
Sustainable development principles for the disposal of mining and mineral processing wastes, Resources Policy, ISSN: 0301-4207, DOI: 10.1016/j.resourpol.2010.12.001
- [5] **Kiventerä J., Golek L., Yliniemi J., Ferreira V., Deja J., Illikainen M.**, 2018
Utilization of sulphidic tailings from gold mine as a raw material in geopolymerization, International Journal of Mineral Processing, ISSN: 0301-7516, DOI: 10.1016/j.minpro.2016.09.008
- [6] **Zhang L.**, 2013
Production of bricks from waste materials – A review, Construction and Building Materials, ISSN: 0950-0618, DOI: 10.1016/j.conbuildmat.2012.09.043
- [7] **Sahu S.K., Kumar M., Sachan A.K.**, 2016
Recycled aggregate concrete with mineral admixtures, Materials Today: Proceedings, ISSN: 2214-7853, DOI: 10.1016/j.matpr.2016.04.051
- [8] **Yellishetty M., Ranjith P.G., Tharumarajah A.**, 2008
Iron ore and steel production trends and material flows in the world: Is this really sustainable?, Resources, Conservation and Recycling, ISSN: 0921-3449, DOI: 10.1016/j.resconrec.2007.01.007
- [9] **Lottermoser B.G.**, 2011
Recycling, reuse and rehabilitation of mine wastes, Elements, ISSN: 1811-5209, DOI: 10.2113/gselements.7.6.405



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