

Revalorization of Coal Waste Facilities: The CRMDataSpace EU Approach

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Abstract

Europe's coal mining legacy is often viewed as an environmental burden, yet closed coal waste facilities may also represent overlooked secondary sources of critical raw materials. The CRMDataSpace project responds to this challenge by developing a harmonized European data infrastructure to assess CRM potential in closed extractive coal waste facilities. This paper presents the project framework, pilot sites in Germany, Spain, Romania and Poland, and the German case study of iron-rich mine water treatment sludge from the former Ibbenbüren coalfield. It shows how standardized data and material characterization can support more transparent revalorization strategies for post-mining regions.

Keywords: Critical raw materials, mine waste, tailings sludge, data space, data integration, land reuse, resource estimation

Introduction

Historical coal mining activities across Europe have generated large volumes of waste materials, including waste rock dumps, tailings from coal processing, and residues derived from mine water treatment. These deposits form extensive anthropogenic accumulations distributed throughout historical coal basins and represent long-term environmental and management challenges in post-mining regions.

At the same time, Europe faces an increasing demand for critical raw materials (CRMs) required for the energy transition, including renewable energy technologies, digital systems, and advanced manufacturing. In response to growing supply risks and geopolitical dependencies, the European

Union has introduced new policy instruments to strengthen resource security, including the Critical Raw Materials Act (CRMA) (European Union, 2024).

Within this context, increasing attention is being given to secondary anthropogenic deposits generated by historical mining activities. Mine wastes are increasingly investigated as potential sources of valuable metals and critical raw materials. These materials, often historically considered non-valuable, may still contain relevant concentrations of rare earth elements and other critical metals that could be recovered through reprocessing and circular economy strategies (Vitti & Arnold, 2022; Tayebi-Khorami *et al.*, 2019; Flores *et al.*, 2025). Furthermore, mine-water treatment



residues represent a particularly relevant case, especially in regions where mine water management continues after mine closure. During treatment processes, dissolved iron and other metals precipitate as hydroxides and oxides, forming sludge deposits that may act as effective sorption phases for trace metals and rare earth elements (Reker *et al.*, 2022; Reker & Westermann, 2025).

In this context, several research initiatives are exploring the potential revalorisation of mining wastes through re-mining approaches and integrated resource assessments. The CRMDataSpace project, funded by the EU Research Fund for Coal and Steel (RFCS), aims to assess the recovery potential of critical raw materials from closed extractive coal waste facilities across several European coal regions while developing a harmonized digital data infrastructure to support resource assessment and sustainable post-mining land management.

The CRMDataSpace Project

The project “Common European Data Space on Critical Raw Materials for the Green Deal: Recovery Potential from Closed Extractive Coal Waste Facilities” (CRMDataSpace) focuses on the identification, characterization, and evaluation of coal-related waste facilities that may host critical raw materials.

The main objective is to develop a standardized European framework for assessing CRM potential in closed extractive coal waste facilities and to establish a structured data space integrating geological,

geochemical, environmental, and technical information related to these sites.

The methodological framework combines several components: (1) identification and inventory of coal-related waste facilities, (2) field sampling and material characterization, (3) geochemical and mineralogical analyses, (4) evaluation of environmental and technical constraints, and (5) integration of results into a European data space.

These activities aim to support the development of circular economy strategies for mining regions undergoing post-mining transition while improving the management of legacy mining wastes. As illustrated in Figure 1, the CRMDataSpace methodological framework operates on two complementary levels: the development of a harmonized data infrastructure and the application of integrated datasets for resource assessment, AI-assisted analysis, and circular economy strategies.

The upper level of Figure 1 represents the development of the data infrastructure, including data collection from closed extractive coal waste facilities, creation of a harmonized data catalogue, and the implementation of a Minimum Viable Data Space (MVDS) contributing to the future European Data Space on Critical Raw Materials. The lower level illustrates the application layer, where integrated datasets support AI-assisted resource estimation, development of business models, and knowledge transfer activities for the sustainable revalorisation of coal mining wastes.

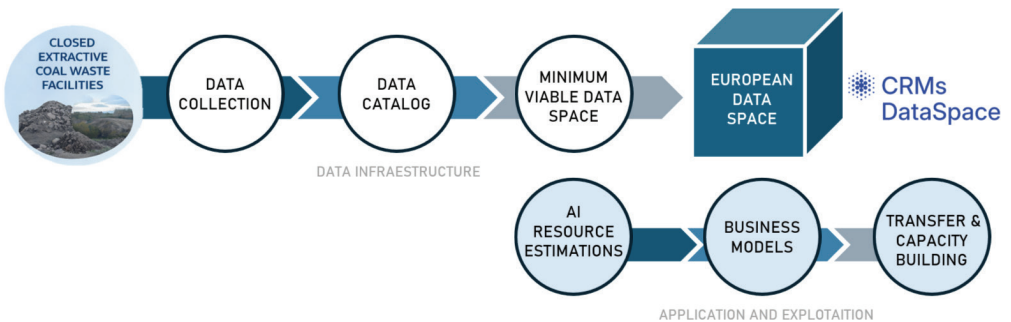


Figure 1 Conceptual framework of the CRMDataSpace project showing two complementary levels.

Pilot Sites Across European Coal Regions

The CRMDataSpace project currently investigates several pilot sites representing different types of coal-related waste facilities. These include mine waste dumps, coal processing residues, and sludge deposits generated during mine water treatment. Figure 2 illustrates the general investigation workflow applied across the pilot sites. The assessment typically begins with field reconnaissance and surface sampling aimed at obtaining an initial geochemical screening of the waste materials. Based on this preliminary evaluation, additional investigations such as hydrometallurgical testing and, where applicable, exploration drilling may be carried out to characterize deeper waste layers and support resource estimation. The final stage consists of integrating the generated datasets into the CRMDataSpace data infrastructure.

In Germany, the project investigates sludge deposits generated at the Gravenhorst mine water treatment plant in the former Ibbenbüren coalfield. These deposits consist of iron-rich sludge accumulated during several decades of mine water treatment operations.

In Spain, investigations focus on historical coal waste heaps located in the Asturias mining region. The San Nicolás waste dump is currently being evaluated through exploratory drilling campaigns and systematic sampling to characterize the geochemical composition of the deposited materials.

In Romania, the project includes the Petrla mine waste dump located in the Jiu

Valley coal basin. This deposit represents a large accumulation of coal mining waste generated during decades of underground mining activities.

In Poland, several coal-related waste deposits from the Upper Silesian coal basin are being investigated to evaluate their potential as secondary sources of critical raw materials.

These pilot sites represent different geological settings, waste formation processes, and environmental conditions, providing a test framework for the standardized methodology developed within the project.

Case Study: Mine Water Treatment Sludge at Ibbenbüren (Germany)

The German case study focuses on sludge deposits at the Gravenhorst mine water treatment plant, located near Hörstel in the former Ibbenbüren coal mining district in North Rhine-Westphalia. Following the closure of the Ibbenbüren hard coal mine in 2018, long-term mine water management became part of the perpetual post-mining obligations, managed by RAG Foundation, associated with former underground coal mining operations in Germany (RAG-Stiftung, 2022).

At the Gravenhorst facility, mine water emerging from underground workings is treated before its discharge into the regional river system. During treatment, dissolved iron and other metals precipitate as hydroxides and oxides. These precipitates are separated from the treated water and deposited in nearby sludge tailing ponds. Over several decades

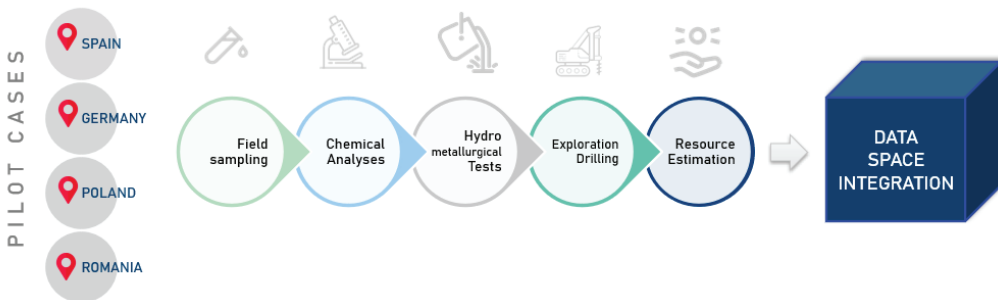


Figure 2 Investigation workflow applied across the CRMDataSpace pilot sites.



of operation, this process has resulted in the accumulation of substantial volumes of iron-rich sludge.

The sludge deposition complex consists of four main ponds with a combined surface area of approximately 257,000 m², with estimated sludge thicknesses ranging between 2 and 4 m (Reker & Westermann, 2025). This corresponds to an estimated total sludge volume between 472,000 and 944,000 m³, representing a substantial accumulation of mine water treatment residues associated with long-term mine water management.

These materials are mainly composed of ferric hydroxides, iron oxides, manganese oxides, gypsum, and fine-grained clay particles (Flores *et al.*, 2024). Such mineral phases are known to efficiently adsorb trace metals and potentially concentrate elements of economic interest (Reker *et al.*, 2022). Previous studies have suggested that these sludge deposits may host recoverable quantities of several metals, including iron, manganese, aluminium, and trace amounts of critical raw materials such as cobalt and rare earth elements. Estimated recoverable quantities reported for the Ibbenbüren sludge deposits are summarized in Table 1 (adapted from Reker & Westermann, 2025).

These estimates represent a conservative scenario, as the deeper layers of the sludge deposits may contain higher metal concentrations. This enrichment may be related to the first flush effect, a process commonly observed during the early stages of mine flooding and mine water discharge, where elevated concentrations of dissolved metals are mobilized and subsequently

precipitated during treatment (Younger, 1997).

An overview of the sludge tailing ponds associated with the Gravenhorst mine water treatment plant is shown in Figure 3.

Planned Sampling and Characterization

Sampling activities are planned within the CRMsDataSpace project to characterize the geochemical and mineralogical composition of the Ibbenbüren sludge deposits. Laboratory analyses will focus on trace metals and potential critical raw materials associated with iron-rich mine water treatment residues, supporting the evaluation of their potential role as secondary resources.

Conclusions

Coal mining waste deposits represent an important, yet largely underexplored potential source of critical raw materials in Europe. The CRMsDataSpace project represents one of the first coordinated European initiatives aimed at developing a standardized framework for assessing the CRM potential of coal-related waste facilities. The investigation of pilot sites in Germany, Spain, Romania, and Poland provides a unique opportunity to evaluate the applicability of common methodologies across diverse geological settings, waste formation processes, and environmental conditions.

The German case study at Ibbenbüren highlights the potential importance of mine water treatment sludges as secondary anthropogenic deposits enriched in iron hydroxides and associated trace metals. Ongoing sampling and laboratory characterization will provide further insights

Table 1 Estimated recoverable metals from Ibbenbüren mine water sludge deposits (adapted from Reker & Westermann, 2025).

Element	Estimated Recoverable Amount (t)
Fe	88,000 – 176,000
Mn	3,000 – 6,000
Al	2,400 – 4,800
Ni	90 – 180
Ti	75 – 150
Co	65 – 130
REEs	20 – 40

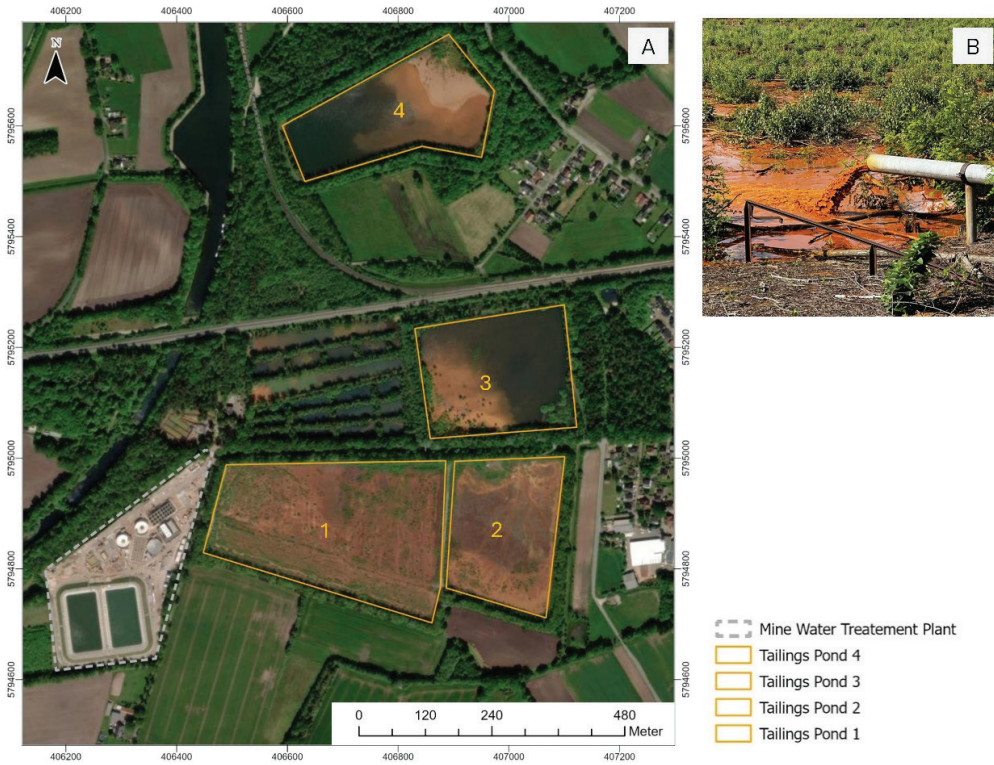


Figure 3 Overview of mine water treatment residues investigated in Germany. (A) Orthophoto showing the sludge tailing ponds associated with the Gravenhorst mine water treatment plant from the former Ibbenbüren coalfield. (B) Field photograph illustrating iron-rich sediments produced during mine water treatment (Photography by Hernan Flores).

into the geochemical composition of these materials and their potential contribution to future circular resource strategies and the sustainable recovery of critical raw materials from legacy coal mining wastes.

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References

European Union, 2024. Regulation (EU) 2024/1252 of the European Parliament and of the Council of 11 April 2024 establishing a framework for ensuring a secure and sustainable supply of critical raw materials (Critical Raw Materials Act). Official Journal of the

European Union. Available at: <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32024R1252>

Flores, H., Reker, B., Pawlik, M., Haske, B., Rudolph, T., 2024. Hyperspectral UAS-sensing for tailing ponds monitoring: Towards responsible resource repurposing. In: Kleinmann, B., Skousen, J., Wolkersdorfer, C. (Eds.), West Virginia Mine Drainage Task Force Symposium & 15th International Mine Water Association Congress. Morgantown, WV, USA, pp. 196–202.

Flores, H., Rudolph, T., Benndorf, J., 2025. Multi-scale characterization of mine waste in a circular economy: Challenges and opportunities. In: Valente, T., Mühlbauer, R., Ordóñez, A., Wolkersdorfer, C. (Eds.), International Mine Water Association Conference – Time to Come. Braga, Portugal, pp. 319–325.

RAG-Stiftung, 2022. The RAG Foundation at a glance. Available at: <https://anrep.rag-stiftung.de/2022/the-rag-stiftung-at-a-glance.html> accessed 05 March 2026).

Reker, B., Westermann, S., Melchers, C., 2022. Mine waters as a resource of critical raw materials in



- Germany. *GeoResources*, 4, 43–47. Available at: <https://www.georesources.net/cms.php/de/journals/865/Grubenwaesser-als-Ressource-kritischer-Rohstoffe-in-Deutschland>
- Reker, B., Westermann, S., 2025. Re-mining of mine water sludges in Germany: An opportunity? In: Valente, T., Mühlbauer, R., Ordóñez, A., Wolkersdorfer, C. (Eds.), *International Mine Water Association Conference – Time to Come*. Braga, Portugal, pp. 807–812.
- Tayebi-Khorami, M., Edraki, M., Corder, G., Golev, A., 2019. Re-thinking mining waste through an integrative approach led by circular economy aspirations. *Minerals*, 9(5), 286. <https://doi.org/10.3390/min9050286>
- Vitti, C., Arnold, T., 2022. Mine waste as a potential source of critical raw materials: A review. *Mineral Economics*, 35, 1–14. <https://doi.org/10.1007/s13563-021-00264-0>
- Younger, P.L., 1997. The longevity of mine water pollution: A basis for decision-making. *Science of the Total Environment*, 194–195, 457–466. [https://doi.org/10.1016/S0048-9697\(96\)05383-1](https://doi.org/10.1016/S0048-9697(96)05383-1)