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11th INTERNATIONAL CONFERENCE ON SUSTAINABLE DEVELOPMENT IN THE MINERALS INDUSTRY

Sustainable supply of critical raw materials

Proceedings

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Foreword

We are pleased to present to you the proceedings of the 11th International Conference on Sustainable Development in the Minerals Industry (SDIMI), held in Torino, one of the undisputed cultural and scientific capitals of Italy, between July 9 and 11, 2024.

This conference and the accompanying proceedings celebrate a journey that commenced in 2003 in the historic town of Milos, Greece, when the landmark MILOS DECLARATION was adopted.

The MILOS DECLARATION represents a statement of our collective contribution to a sustainable future using scientific, technical, educational, and research skills and knowledge in minerals extraction and utilization that was endorsed by the leading global professional and scientific organizations and institutes representing the minerals professionals.

SDIMI 2024 brings the International Scientific Community actively engaged in Sustainable Development in the Minerals Industries back to Europe, after an exciting conference in Namibia in 2022, just a couple of months after the adoption of the EU Critical Raw Materials Act, and just two weeks after the response of the Italian Government (Decree 84 of June 25, 2024).

Critical raw materials are today at the centre of the political agenda of nearly all countries worldwide and at the core of the on-going energy and digital transitions, with a forecasted demand increase for minerals and metals by a factor two to four on average by the year 2050 and reaching 60-fold for some key materials.

Mineral user-countries are multiplying their efforts to promote secure and sustainable critical minerals supply chains, as they acknowledge their external dependence. At the other end of the spectrum, mineral producer-countries are formulating strategies to leverage their critical mineral industry and expand their role in the global value chains.

Significant examples of user-countries are the EU, United States, Japan, Korea, etc., for which the following statement of the EC President Ursula von der Leyen can summarise the key issue: "*without a secure and sustainable access to necessary raw materials, the European ambition to become the first climate neutral continent is at risk*".

A quite different, but complementary, approach is that of mineral producer-countries such as Australia, Brasil, Canada, Namibia, South Africa, etc., which are looking to expand their global role as critical materials supplier and manufacturer, moving into downstream processing and thus capturing more value, keeping economic benefit and jobs, and boosting their sovereign capability.

Everybody wants a "*secure and sustainable supply*" of minerals and metals, but "*sustainable supply and use*" need an honest and frank dialogue among academia, governmental bodies, civil society, industry, and community in order to re-build trust, complement each other capabilities and reach common or complementary goals. SDIMI is the ideal platform for such a dialogue.

Our most sincere gratitude goes to the organising committee, particularly Dr. George Barakos, who worked tirelessly to put together the conference and this collection of abstracts. We also extend our gratitude to Symposium for organising this conference and to local organizing committee for their exceptional level of commitment and dedication. Thanks also to the authors and the reviewers who have committed a remarkable time and effort to put together such an exciting programme. The abstracts, extended abstracts and short papers presented in this book of proceedings were peer reviewed by the scientific committee. We also wish to extend our deepest gratitude to the keynote speakers for accepting our invitation.

Once again, we thank everyone for participating in this conference in their various complementary roles and capacities.

Professor Marilena Cardu and Professor Gian Andrea Blengini

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Keynote Speakers

Antoine Beylot

Short Bio:

Antoine Beylot has been a research engineer at BRGM (the French Geological Survey) since 2011. In 2018-2019, he served as a project officer at the Joint Research Centre of the European Commission. His research activities focus on LCA and Input-Output Analysis, with application to raw materials (primary and secondary) production, including metals.

He has been involved in more than 20 national and EU projects since the start of his career. He moreover supports French Ministries in the context of raw materials-related EU policies (including the EU Battery Regulation and CRM Act), for what regards environmental footprint quantification.

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Laurence Dyer

Short Bio:

A/Prof. Laurence Dyer leads the Metallurgical Engineering program from Curtin University's historic Kalgoorlie campus in the heart of Western Australia's Goldfields. Originally trained in chemistry and physics, he has spent more than 15 years in education and industry-based research in extractive metallurgy and has a passion for developing solutions that both improve business and sustainability outcomes.

Since taking the role in Metallurgical Engineering at Curtin, Laurence has conducted research in processing flowsheets across an array of critical and precious metals. His drive to produce graduates ready to join the industry and focus on applied outcomes of his research has nurtured a strong network of mining, METS, government and community bodies. These have led to the expansion of his research into water treatment, waste management and supply chains. This was supported through his position as Technical Advisor of the Kalgoorlie-Boulder Mining Innovation Hub, established by CRC ORE and now part of Curtin University.

Associate Professor Dyer is currently the Deputy Head of School (Metallurgical Engineering) of the WA School of Mines: Minerals, Energy and Chemical Engineering, and the Interim Manager of Curtin's Gold Technology Group.

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Paul Elkins

Short Bio:

Paul Ekins has a Ph.D. in economics from the University of London and is Professor of Resources and Environmental Policy at the UCL Institute for Sustainable Resources, University College London.In 2011 he was appointed Vice-Chairman of the DG Environment Commissioner’s High-Level Economists Expert Group on Resource Efficiency, and in 2012 a member of the European Commission’s European Resource Efficiency Platform.

In 2013 he was appointed to UNEP’s International Resource Panel (IRP), for whom he was lead author of a major report on resource efficiency at the request of the German Government at the G7 Summit in 2015. He is now lead coordinating author for a forthcoming IRP report on critical minerals.

He was one of two Co-Chairs of UNEP’s sixth Global Environment Outlook (GEO-6), published in March 2019. In 1994 Paul Ekins received UNEP’s Global 500 Award ‘for outstanding environmental achievement’ and in 2015 an OBE for services to environmental policy.

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Milan Grohol

Short Bio:

Mr. Milan Grohol, PhD is a Policy Officer in the Unit of Energy intensive industries and Raw Materials at the Directorate-General for Internal market, Industry, Entrepreneurship and SMEs (DG GROW), European Commission.

Since 2004, he contributes to the EU raw materials policy and initiatives, including the programming of Horizon funding on raw materials. He leads the EU assessment of the Critical and Strategic Raw Materials, and the organisation of the EU Raw Materials Week since 2016.

He represents DG GROW in the Bureau of the UNECE Expert Group on Resource Management since 2018. He also contributed to the development of the Critical Raw Materials Act.

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Michael Hitch

Short Bio:

Dr. Michael Hitch is a leading voice in challenging the conventional wisdom surrounding sustainable development and critical mineral theory. With a PhD in environmental and resource management from the University of Waterloo, Canada, he brings a critical perspective to these topics.

Through rigorous research and analysis, Dr. Hitch dismantles the simplistic narratives often associated with sustainable development, arguing for more nuanced approaches that account for economic, social, and environmental complexities. Similarly, he questions the prevailing assumptions of the critical mineral theory, advocating for a broader consideration of resource management that prioritises resilience and equity as opposed to the capitalistic interests of mining companies.

Dr. Hitch's work encourages dialogue and innovation in redefining our understanding of sustainability and mineral resource governance.

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https://www.ufv.ca/science/deans-office/hitch-michael.htm

Serkan Saydam

Short Bio:

Serkan Saydam received his BSc, MSc and PhD degrees in Mining Engineering from the Dokuz Eylul University, Izmir, Turkey and completed his Postdoctoral Fellowship at the University of Witwatersrand, Johannesburg, South Africa. He then worked at De Beers for three years as a project manager in Johannesburg, South Africa.

Serkan joined the School of Mining Engineering as a Senior Lecturer in 2006 and since 2017 he has been working as a professor. He is currently Chair of Mining Engineering at the School of Minerals and Energy Resources Engineering at UNSW. A key focus of his research is to address the current needs and future challenges the minerals industry faces. These are generally complex engineering problems as mining environments become more extreme and constraints are imposed due to increasing social, environmental, and health and safety standards. His fields of research include space resources engineering, ground control, mine systems design, mine internet of things, and technology integration and management. He established research collaborations with NASA, ESA and Luxembourg Space Agency, and KICT, as well as more than 40 research organisations and universities globally.

He has more than 250 publications and graduated 20 PhD students. Serkan attracted more than $15M in research grants. Serkan is known for founding and chairing the AusIMM's International Future Mining Conference Series and co-chairs AusIMM's AusRock Conference Series and Off-Earth Mining Forums. Professor Saydam received multiple academic awards, including the 2020 UNSW Dean's Award for Global Impact, the 2019 UNSW Vice Chancellor's Postgraduate Research Supervision Award and the 2017 Society of Mining Professors' Tim Shaw Innovation in Teaching Award.

Serkan is currently a Fellow Member of the AusIMM; President of the ISRM Commission on Planetary Rock Mechanics; Deputy Director of the Australian Centre for Space Engineering Research (ACSER) at UNSW; Deputy Secretary-General and Council Member of the SOMP (Society of Mining Professors). Prof Saydam is also President for 2023/2024 of the SOMP.

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Slavko Solar

Short Bio:

Dr. Slavko Solar is a Mineral Resource Geologist who worked as an exploration geologist, Head of Department, consultant, policy adviser for the Slovenian government and industry on minerals, resource management and sustainability, besides he was coordinator of many projects and the Mining Public Service, all at the Geological Survey of Slovenia.

Since 2012, before becoming Economic Affairs Officer at UNECE dealing with UNFC implementation in Europe in July 2021, he was a Secretary General of EuroGeoSurveys (September 2017- June 2021), a Senior Scientific Officer at DG Joint Research Centre (JRC) (November 2016/ August 2017), and a Seconded National Expert to DG GROW (October 2012 – September 2016).

He has an extensive list (# 08253) of publications related to his expertise published in journals and conference proceedings.

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Michael Karmis

Short Bio:

Michael Karmis is Stonie Barker Professor of the Mining and Minerals Engineering Department, Virginia Tech and director of the Virginia Center for Coal and Energy Research.

He earned his BS and PhD degrees in Mining Engineering from Strathclyde University, Scotland. He has authored more than 150 scientific papers, reports, Proceedings volumes and textbooks. He has directed or co-directed about 40 major research projects and has served as advisor to 30 post-graduate students.

Dr. Karmis has been active within the Society for Mining, Metallurgy and Exploration (SME), has served for 10 years on the SME Board of Directors, and he was the 2002 SME President. A professional engineer in the USA, and a licensed engineer (Eur Ing) in Europe, Dr. Karmis has been active in consulting with the minerals industry, consulting companies, government organizations and legal firms.

He is a Distinguished Member of the SME, a Fellow of the Institute of Quarrying and a Fellow of the Institute of Mining and Metallurgy. He has received numerous recognitions and awards from major scientific, professional and industrial organizations.

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Conference Proceedings

Recovery Metallurgy

Recovery of Magnesium Hydroxide from Brines of Potash Mining: An Optimized Approach

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Keywords: *Magnesium hydroxide; Valorization of brine; Design of Experiments; Potash mining industry; Resource recovery*

Abstract

The potash mining industry generates large quantities of hypersaline liquid waste (brines) resulting from the extraction of ore, particularly carnallite. Conventional disposal methods pose environmental risks and result in the loss of potentially valuable minerals. This study aims to address this issue by investigating the recovery of magnesium hydroxide ($Mg(OH)_2$) from potash brine through a reactive crystallization technique. Response surface methodology was used to optimize the precipitation of $Mg(OH)_2$, taking into account the concentration of the precipitant, reaction time, and temperature. The conditions to achieve optimal recovery of high purity magnesium hydroxide include the use of a 2 M precipitant and a reaction time of 40 minutes at 60°C. The proposed model is validated, in terms of reliability and precision, by a very good agreement between predictions and experimental results, attested by a coefficient of determination greater than 0.98. Mineralogical and chemical analyses confirm the high purity of recovered $Mg(OH)_2$.

This novel approach not only provides a means to manage brine waste but also holds the potential to capture magnesium hydroxide as a by-product, thereby promoting environmental sustainability and economic benefits for the potash mining sector.

Alternative Flowsheet for Rare Earth Processing

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1. Introduction

The latter stages of the 20th century and the new millennium have witnessed expansion of use of rare earth elements (REE) in existing and new applications. These elements are often indispensable, and claims are made that replacement materials either do not work, or provide inferior capability or performance (King, n.d.). While the moniker suggests limited availability, the elements are widespread and common, but they are typically distributed in dilute form and economic resources are relatively scarce (Gupta et al., 2004). Recovery to pure products is also relatively complex and difficult (Verbaarn et al., 2015).

Production capacities and requirements are currently relatively small (Gambogi, 2020). However, market conditions, including conversion to using increased renewable energy, an area where these elements have demonstrated superior performance, will lead to increased demand. Monopolistic market conditions with few global producers are regarded as having stifled innovations, not just in the processing, but also in areas where technology advancement is regarded critical. This has reinspired evaluations regarding availability of supply (CSIRO, 2015).

Mineral deposit exploitation requires treatment of non-renewable resources, somewhat at odds with a pure sustainable development definition. The minerals industry has therefore realigned to the bigger goal of sustainability, where the societal needs of the present are met by efficient use of resources. Factors incumbent in the current scenario are minimisation of environmental impacts along with maximisation of utilisation of resources when these are processed (Milos Statement, 2003).

Conventional processing typically uses high temperature acid or alkaline conditions, with acid bake and water leaching currently prevalent (Demol et al., 2019). Environmentally challenging conditions are experienced and typically a step to upgrade materials to a high grade prior to chemical treatment is included, this to ensure economic recoveries.

Oxalic acid was shown to provide an alternative to conventional processing since it is capable of attacking monazite to solubilise phosphorus and release contained rare earth elements (Lazo et al., 2017). Processing is possible at temperatures of around a mere 45°C (Henderson et al., 2022). REE rendered insoluble in the oxalic system precipitate. Subsequent treatment with EDTA at elevated solution pH has been used for resolubilisation, allowing subsequent collection as oxides followed by redissolution and conventional solvent extraction (Lazo et al., 2018).

2. Materials & Methods

A rare earth concentrate was used in experimentation, with this allowing a relatively consistent feed grade for comparative evaluation and determination of aspects of the chemistry which were not well understood. The concentrate contained approximately 10.2 percent air-dried moisture. Loss on ignition determinations indicated significant heat degradable components, including mineral bound water and carbonate, at approximately 7.7% content.

Table 1. Concentrate grade parameters

Component	Grade (wt %)
CeO_2	14.73
La_2O_3	8.78
Nd_2O_3	5.95
Pr_6O_{11}	1.87
P2O5	16.62
Fe_2O_3	26.62

A baffled tank with active volume of approximately 2.0 litres was used for treating concentrate with 0.8M oxalic acid made up with reagent grade oxalic acid dihydrate. The water-jacketed tank allowed temperature control using a Thermoline Scientific water bath. A three-blade impellor was used in the reactor, with this demonstrated suitable for suspending solids at 100 g/litre solids loading with an approximately 550 RPM motor speed.

A Malvern 3000 Hydro EV machine was used in particle size determinations. The concentrate had a particle size P_{80} of 75 µm, with this changing to P_{80} of 47µm after oxalic acid leaching. Significant below 10 µm material was present in the oxalic acid leach residues subject to treatment with EDTA.

EDTA solubilisation was completed in beaker tests, with solids loadings kept to 100 g/litre and where a magnetic stirrer was used for solids suspension. The EDTA was prepared with reagent grade disodium EDTA added to deionised water brought to approximately pH 10 with 1 M sodium hydroxide. EDTA was prepared to 0.1 M or 0.2 M strengths.

Solids recovery at the end of an oxalic acid leach test was completed using vacuum filtration. Several intermediary samples were also removed during a leach test, with these typically gravity filtered using a number of different filter papers including Whatman No. 1 or No. 2 of varying diameter. No intermediary sampling was performed in the EDTA tests. Filtration of the EDTA slurries at the end of contacting proved challenging as this reagent has dispersant properties. A few filter papers, filter membranes and the use of flocculant were examined for the purpose of solids recovery.

Solution samples were analysed using an Agilent Industries 5100 instrument. Analyses of solids were completed using several methods, including 2-acid aqua regia digestion and ICP-OES analysis, x-ray fluorescence (XRF) completed using a Rigaku 200 Supermini XRF machine, and, x-ray diffraction (XRD) using an Olympus BTX 513 XRD machine was used. XPowder Ver. 2010.01.35 PRO software was used to interpret the diffractograms.

3. Results & Discussion

The oxalic acid used was used without pH adjustment. Typical pH of solutions registered at 0.8 to 1.2 units, with little change observed during tests. Phosphorus and iron were the main components solubilised by the oxalic acid.

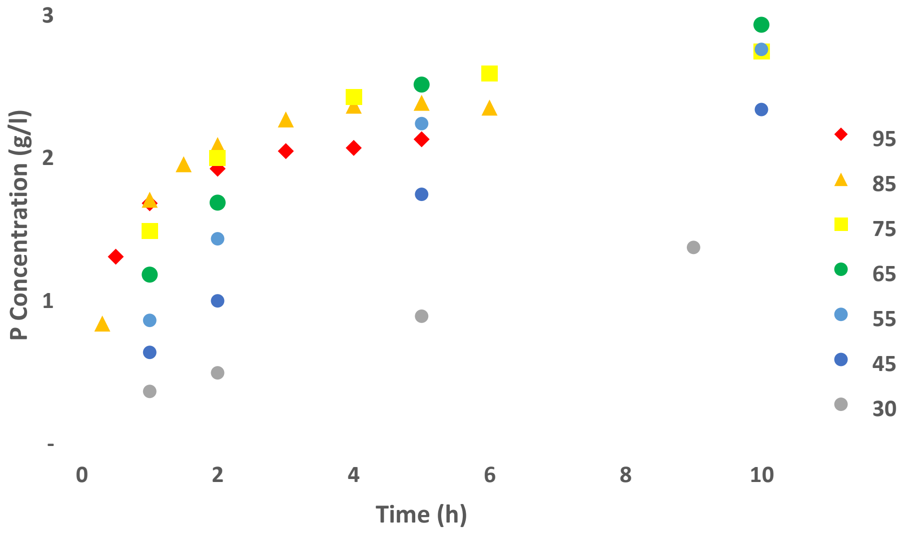

Figure 1. Oxalic acid leaching phosphorus concentrations at various temperatures (°C) (0.8M oxalic acid; pH approximately 1.0; 100 g/litre solids loadings)

This represented dissolution from monazite and goethite respectively. REE concentrations were monitored to ensure these elements deported to residue.

The oxalic acid treatment was demonstrated to have reactions with relatively slow kinetics. The phosphorus reaction initially increased as temperatures increased, but then plateaus were reached where leaching slowed and ceased. Ultimately, the most appropriate temperatures were below 65°C. It was also shown that leaching at 30°C was capable of reaching similar extents of leaching, at near 50 percent dissolution of phosphorus, with sufficient time, in this case about 3 days. Other endeavours indicated leaching at 25°C was ineffectual (Lazo et al., 2017).

Iron leaching, proceeding almost linearly as a function of temperature, significantly increased as temperatures increased. After 10 hours, concentrations of iron exceeded those of phosphorus with temperatures in excess of 55°C. Fortuitously, the extent of iron leaching could be restricted by maintaining temperatures below this. At 45°C, iron concentrations only reached around 1.4 g/l increasing to 2.6 after 48 hours and 3.3 g/l after 72 hours. At 30°C this reduced to 0.9 g/l after 72 hours. Thus, an operating temperature between 30°C and 45°C was appropriate for maximising phosphorus dissolution and minimising iron co-solubilisation.

Several experiments with higher solids loadings were also conducted. These demonstrated phosphorus solubilisation was dependent on oxalate availability, while iron relied on acid reaction, and where this continued relatively independent of oxalate concentration or mineral presence due to extensive buffering of solution with various oxalate and phosphate ions. No benefit was derived from increasing solids loading. While concentrations were higher, these were not increased in direct proportion to the mineral addition. There may in fact be some merit in reducing this loading, but this will require economic assessment to justify.

In the same 24-hour period, iron leaching was demonstrated to be dependent on temperature as the main factor driving the reaction. Although there was a slight offset, presumed due to a minor iron response at introduction of mineral to solution, similar leach curve concentrations were reached.

Minor amounts of aluminium, calcium and magnesium were released to solution following an acid leaching mechanism. On standing, a calcium oxalate precipitate formed. Although only present at minor levels, near limits of detection for the apparatus used, thorium responded in similar manner to calcium, with greater release with elevation of temperature. On standing, thorium also trended downwards. To counter the reduction in leaching with increased solids loadings, processing is preferably conducted in cross-flow staged approach. Where fresh oxalic acid was used, this promoted further reaction, achieving a 65 percent phosphorus dissolution from concentrate.

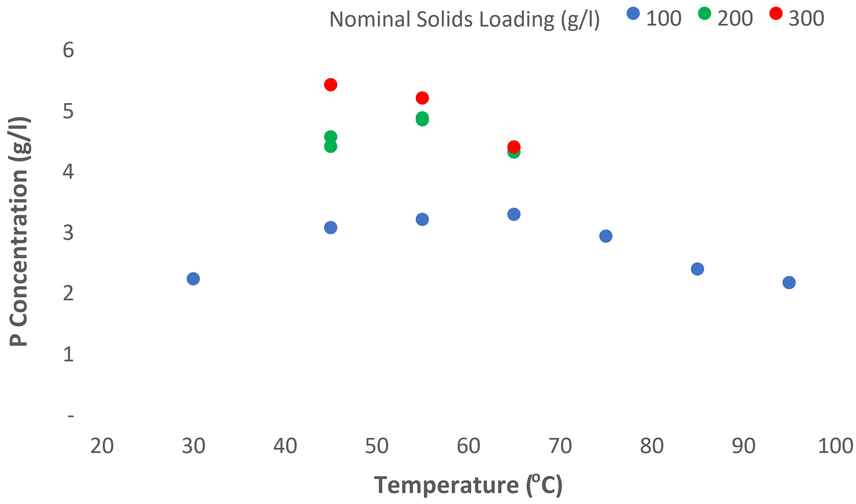

Figure 2. Phosphorus dissolution concentrations after 24 h

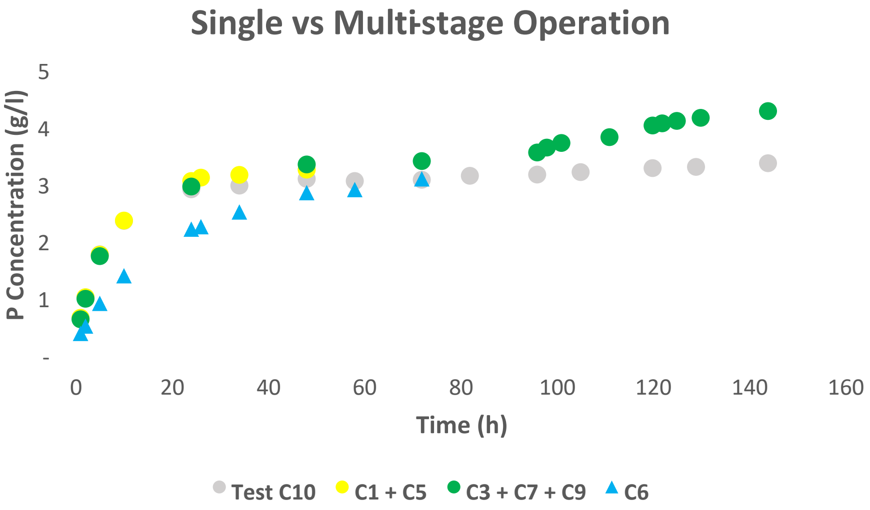

Figure 3. Multi-stage oxalic acid leaching (0.8M oxalic acid; 100 g/l solids loading; 45°C, except C6 at 30°C) (C10, single stage; C1 + C5, two-stage; C3+C7+C9 three stage)

XRD analysis identified the formation of REE oxalates. Effective solubilisation of these REE oxalates originally associated with dissolved phosphorus mineralisation was achieved with 0.2M EDTA and with pH adjustment to maintain elevated pH by alkali addition.

Labelling reflects the oxalic acid leach test from which residue was taken for EDTA treatment.

- C2, a test at 65°C over 24 hours;
- C3, a test at 45°C over 96 hours;

- C4, a test also at 45°C over 72 hours (also increased impellor speed to 705 RPM, resulting in no significant difference in response to that seen in C3);
- C5, a second stage (reprocessing with refreshed oxalic acid);
- C9, a three-stage leach (fresh oxalic acid each time) combined time 144 hours.

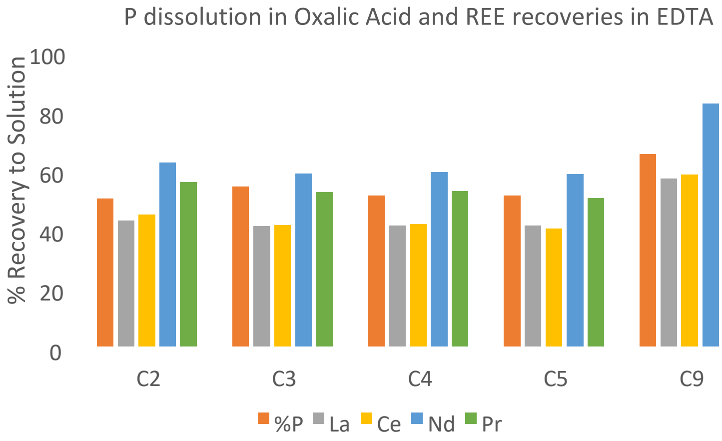

Figure 4. EDTA solubilisation of precipitated REE oxalates (0.2M EDTA; 100 g/litre solids loading; pH kept above 8.0) (%P reflects prior phosphorus dissolution in oxalic acid)

REE concentrations aligned closely with the extent of phosphorus dissolved in the prior oxalic acid leach. There was a trend to preferential dissolution of neodymium and praseodymium over cerium and lanthanum. XRD, XRF and aqua regia digestion results provided support for this observation. There was also minor phosphorus release in excess of the REE content indicating reaction of phosphate mineralisation not containing REE or REE depleted material.

An aspect of leaching highlighted by XRF and XRD analyses of solids included incomplete reaction with a monazite fraction remaining in all residues, including the EDTA residues. This implies a non-responsive monazite component. The XRD results also demonstrated oxalate was removed from the EDTA treated residues.

4. Conclusions

The reactions occurring are complex, and further evaluation of the system has increased understanding of this complexity. Overall, a result near 65 percent phosphorus dissolution was realised using a multi-stage approach. There was a trend to superior neodymium and praseodymium extraction. Low temperatures imply low energy requirements.

While high grade concentrate was treated, the ultimate success for this system is predicted to be through treatment of lower grade concentrates or even ores. These benefits can be tailored to suit Milos objectives in minimising environment impacts and maximising resource utilisation.

5. Acknowledgements

This research is supported by an Australian Research Training Program (RTP) Scholarship.

Appreciation is expressed to staff and students at Curtin University, Kalgoorlie Campus, Western Australian School of Mines (WASM) for guidance, support and assistance with machine operation and various analyses.

6. References

CSIRO (2015). The rare earth challenges. Issue 7. [Article] Resourceful Magazine. Retrieved from: https://www.csiro.au/en/Research/MRF/Areas/Resourceful-magazine/Issue-07/Rareearth-challenge

Demol, J., Ho, E., Soldenhoff, K. and Senanayake, G. (2019). The sulphuric acid bake and leach route for processing rare earth ores and concentrates: A review. Hydrometallurgy 188: 123-139.

Gambogi, J. (2020). Mineral Commodities Summaries: Rare Earths. USGS publication. https://pubs.usgs.gov/periodicals/mcs2020/mcs2020-rare-earths.pdf

Gupta, C.K. and Krishnamurthy, N. (2004). Extractive metallurgy of rare earths. CRC Press.

Henderson, M.S., Dyer, L.G. and Alorro, R.D. (2022). Flowsheet Development for treatment of rare earth ores. In the Proceedings of IMPC Asia-Pacific 2022, Melbourne, Australia, 22-24 August 2022. AusIMM, 535.

King, H.M. (2020). REE - Rare earth elements and their uses. The demand for rare earth elements has grown rapidly, but their occurrence in minable deposits is limited. Retrieved 9 August 2020 from: https://geology.com/articles/rare-earth-elements/#google_vignette

Lazo, D.E., Dyer, L.G., Alorro, R.D. and Browner, R. (2017). Treatment of monazite by organic acids I: Solution conversion of rare earths. Hydrometallurgy 174: 202-209.

Lazo, D.E., Dyer, L.G., Alorro, R.D. and Browner, R. (2018). Treatment of monazite by organic acids II: Rare earth dissolution and recovery. Hydrometallurgy 179: 94-99.

Milos Statement (2003). Contribution of the mineral's professional community to sustainable development. https://sdimi.org/wp-content/uploads/2021/11/SDIMI2003_milos_decl_org.pdf

Verbaarn, N., Bradley, K., Brown, J. and Mackie, S. (2015). A review of hydrometallurgical flowsheets considered in current REE projects. Symposium on critical and strategic materials. British Columbia Geological Survey Paper 2015-3.

Reliable Metal Accounting as a Tool for Sustainability in the Platinum Group Metals Industry – A Case Study of a Zimbabwean Process Plant

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1. Introduction

Sustainability in the production of critical minerals requires that robust metal/mineral accounting be adhered to at all stages of the mineral value chain. The beneficiation process needs to be performed in efficient and reliable ways, with robust and transparent accounting procedures which result in internationally accepted metal reconciliation outcomes. These typically translate to the company balance sheet, thus impacting on the sustainability of the organisation. This research investigated the variability of concentrate grade on different streams in the value chain of a Platinum Group Metal (PGM) mineral processing plant X and its impact on metallurgical accounting. The study involved analysing the accuracy of sampling and assaying techniques, and the precision of measurements taken by weightometers and other monitoring devices.

The research provided insights into the factors that affect metallurgical accounting and their impact on the overall metal balance. The sampling equipment for the three concentrate streams on the plant (combined concentrate, larox feed and filter cake) were analysed to ensure congruency. Accurate and reliable custody transfer systems and procedures are essential for maintaining the integrity of the platinum mineral processing industry and ensuring that each party receives fair value for their share of the PGMs. Generally, there is limited research on this topic in the PGM industry; therefore, the research should add value to this industry.

Metallurgical accounting is an ongoing process that involves sampling, analyzing, and accounting for the valuable metals that are part of the metallurgical circuit (Soni, 2013; Dzinomwa et al., 2015). As the material flows through the processes, samples are taken from different streams and points in the plant to assist in metallurgical accounting and process control. The Australian Mineral Industry Research Association (AMIRA) Code of Practice for Metallurgical accounting has been widely adopted in the industry and has been used as the basis of operation and audits of numerous metallurgical plants. Metallurgical accounting is part of financial accounting and helps in defining production costs and revenues, as well as stocks and inventories as defined in the "Code of Practice for Metallurgical accounting" (Amira, 2007). It is also the baseline for estimating the net value of the company. Metallurgical accounting is based on material balance which is determined from critical measurements.

There are three main factors that affect metallurgical accounting, namely mass measurement, sampling, and analysis. Any uncertainty in measurement, due to the inevitable measurement error, in which the sampling error is generally the main component, results in an unwanted and unnecessary financial risk.

Metallurgical accounting is the estimation of (saleable) metal in process streams over a defined time period. Fundamentals of the metal balance should be developed upon known practice of sampling and sample analysis standards. On the plant used for the case study, there was a significant grade variance between the concentrate streams, namely, flotation concentrate, concentrate thickener underflow and filter cake. The two-product formula uses concentrate grade from flotation in the computation of recovery [(Morisson, 2008). In this research investigation the final product was not complying with the output of the two-product formula and yet the latter would have been used to declare the production ounces. The variance between the production tonnage determined from the two-product formula and the actual production was more than 2%, which was outside the limits stipulated by the AMIRA code of practice. This resulted in financial discrepancies hence the need for this research.

Metal accounting has financial implications on cost and budgets. Financial accounting for the organization was based on the metal balance across the mineral processing value chain, therefore it was critical to ensure that metal balance was done to the expected metallurgical accounting standards. The objectives of this study were to analyse sampling practices (in relation to standards) and their effects on metallurgical accounting, and also to evaluate sampling errors and sources of variances between the three streams namely, flotation concentrate, concentrate thickener underflow and filter cake. Then quantifying the financial threat of improperly tuned sampling and metallurgical accounting on the selected case study.

2. Materials & Methods

This section involved compilation of historical data, trends analysis, identifying deviations from expected standards and justifying the historical data trends. Analyzing historical data involved examining data from past processes in order to identify patterns, trends, and insights that could inform decision-making in the present or future. One key benefit of analyzing historical data was that it could provide valuable insights into the underlying factors that had contributed to the past. By examining patterns and trends in data over time, analysts can gain a better understanding of what has worked well in the past and what may need to be improved upon in the future.

Another benefit of historical data analysis is that it can help to identify potential future trends and patterns. By examining past data and looking for indicators of future trends, analysts can make more informed predictions about what may happen in the future and how best to prepare for potential outcomes. Historical data analysis is a powerful tool that can be conducted using a variety of tools and techniques, including statistical analysis, data visualization, and machine learning. It is important to ensure that the data being analyzed is accurate and reliable, and that any conclusions drawn from the analysis are based on sound reasoning and careful interpretation of the data.

Data was collected in an extensive and systematic manner, which was designed to enable determination of answers to the primary questions being investigated on the topic to prove hypotheses and evaluate the results. The methods of collecting data used in this project were circuit survey, circuit direct observations and document reviews. Analyzed streams were the combined concentrate, thickener underflow, clarifier underflow, Larox PF (filter feed, cake, filter cloth wash water stream). The Larox PF filter cloth wash water stream and filter cake were sampled cycle by cycle. This was to check if there was a correlation or an established relationship between the final concentrate and the final filter cake grade over a long period of time from 22-06-2014 to 30-06-2022.

3. Results & Discussion

36% (2.8 tph) of feed to the concentrate thickener from flotation of 5.1 to 7.8 tph of solids, failed to settle and was carried off to the clarifier as feed and all the remaining solids settled in the clarifier. Clarifier feed contained very fine material which took a long time to reach the desired target density of 1.6 kg/l to be transferred to Larox Filter feed tanks. However regardless of the high grade of Clarifier underflow, the stream was not transferred frequently as the thickener underflow hence another source of variance between Final concentrate and filter cake discharge.

On the trend shown in Figure 2, concentrate grade was always above the filtered cake grade regardless of the different process plant patterns. The causes of trend variation between the regions shaded, blue, green, and yellow, particularly the blue region (from 20 to 30 June 2014) was that the flotation circuit mass pull increased from 2.0 to 2.5%.

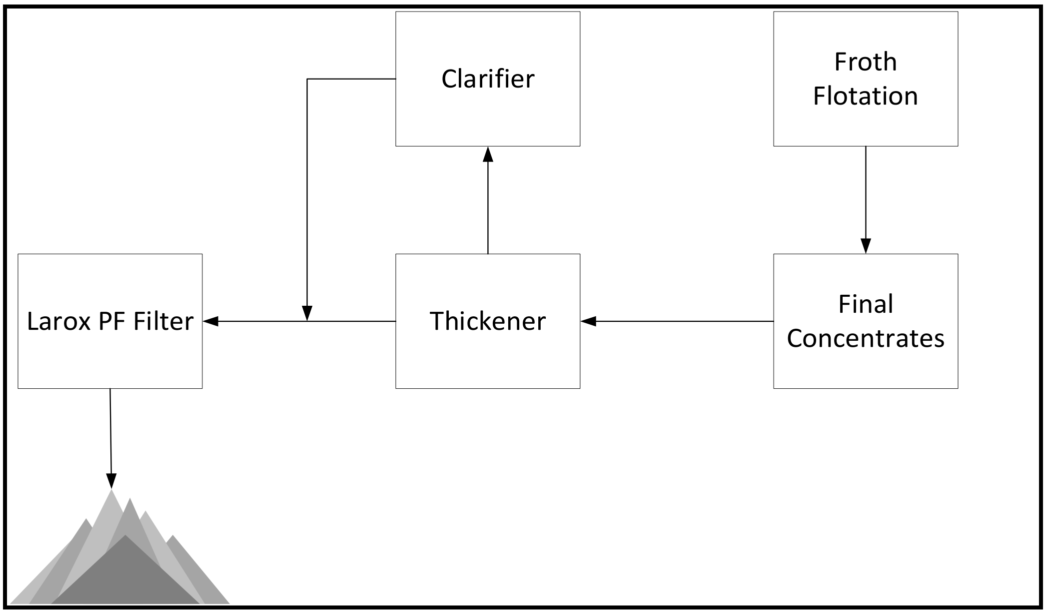

Figure 1. Mass balance circuit configuration

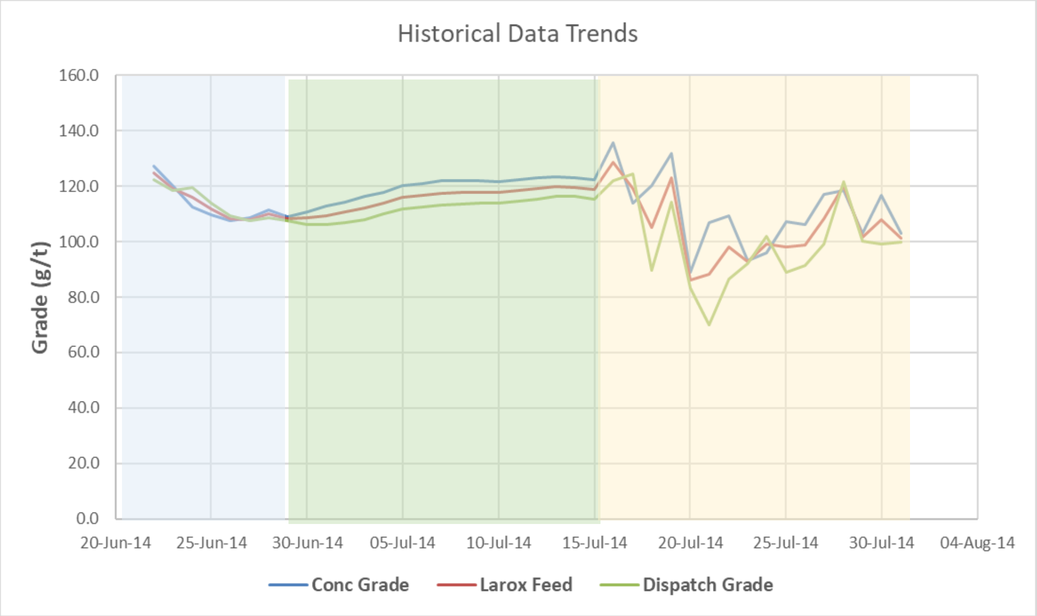

Figure 2: Historical Data Trends

Meanwhile, in the green region (from 30 June to 15 July 2014) the final concentrate grade improvement initiatives were introduced, and makeup water was introduced in the final concentrate sump to have a consistent sample cut. In the yellow region 15 to 30 July 2014, reagent optimizations were implemented, and new reagents were being tried in an effort to manage operational cost. Mill feed grade was also going on a downward trend thus affecting final concentrate grade.

The mass fraction by elemental distribution by size in Figure 3 shows that there was a significant small fraction in the final concentrate stream. As a result, the discrepancy would report to the clarifier due to the fines' respective small densities (settling kinetics). This fines portion was then not sampled in the thickener underflow sample despite the fact that the fines fraction had higher grade than that of the coarse fraction.

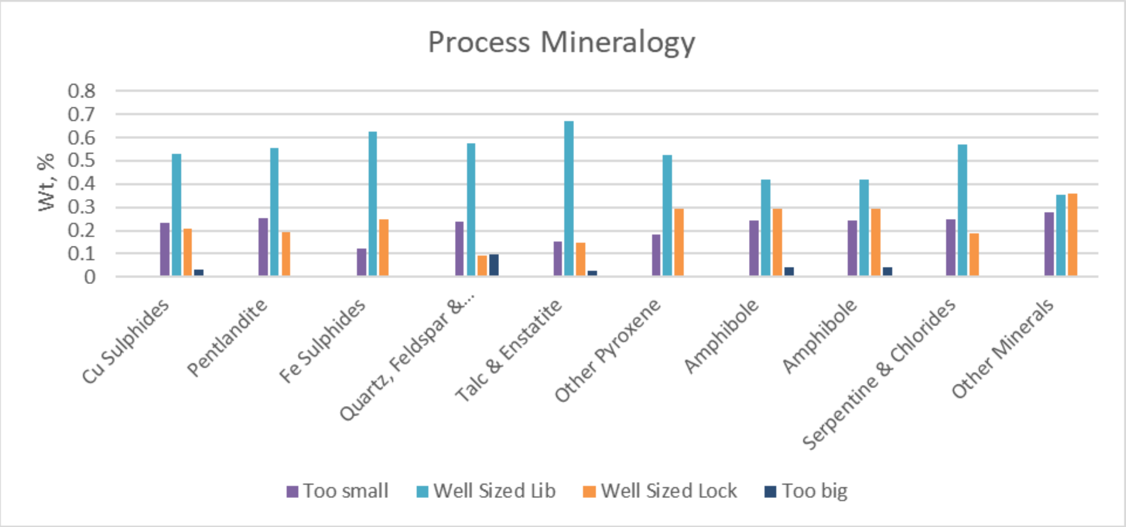

Figure 3. Graph Mass fraction by elemental distribution by size.

4. Conclusions

From historical trends analysis, it could be concluded that the final concentrate sample from floatation was higher than Larox feed which was also higher than filter cake. This would lead to discrepancies in metallurgical accounting. The frequencies for cutters and cutter gaps needed to be set as per flow rates and particle size requirements. The sample cutter from the flotation concentrate had periodical inconsistent flow due to requirements of flotation at the given time and this led to non-representative sampling. The small fine fraction from the thickener reported to the clarifier and was thus not sampled in the thickener underflow which was the Larox feed. This sample's grade was bound to be understated and hence to be lower than the final concentrate sample. Ultimately, this was inaccurate for metallurgical accounting. On filter cake, the filter cloth wash water had a contribution of fines which did not immediately report to the filtered cake. The contribution from this exercise was deemed to be small but it must be noted that there was a slight variation. The auger sample from the trucks was not as accurate as the automatic sample cutter set at certain frequencies.

To resolve the metal accounting challenge in this case study, the proposed recommendations from the study were as follows. Water addition to be made to the sump for the final concentrate sump so that there would always be consistent flow when the cutter cuts the stream.

Further research was required into the possibility of redesigning the sample cutter for the combined flow of thickener underflow and clarifier underflow. Options of installing a sample cutter on clarifier underflow were an alternative solution.

After implementing the above two recommendations, either final concentrate sample or Larox filter feed could then be considered for final metallurgical accounting stream in the two-product formula.

Any losses of metal during the production process impact negatively on metallurgical accounting and the confidence of stakeholders in the financial accounting of the company. Reliable metal accounting assists with accurate and timely reporting, which is essential to maintaining compliance with regulations and hence the sustainability of the organisation.

5. References

Amira, P. (2007). Metal Accounting. In Code of Practice and Guidelines.

Dzinomwa, G., Gumbie, M., Katiyo, B. and Chinyakata, F. (2015). Mined Ore Reconciliation and Metal Accounting. In the proceedings of the SAIMM Conference on Metal Recovery and Accounting, Harare, Zimbabwe.

Holmes, R.J. (2004). Sampling of mineral and measurement - The fundamental of metallurgical accounting, Chemometrics and Intelligent Laboratory Systems

Holmes, R.J. (2004). Correct sampling and measurement—the foundation of accurate metallurgical accounting, Chemometrics and Intelligent Laboratory Systems, *74*(1): 71-83.

Morrison, R.D. (2008). An Introduction to Metal Balancing and Reconciliation, Julius Kruttschnitt Mineral Research Centre.

Soni, P. (2013). Blogs," SAP. Retrieved from: https://blogs.sap.com.

Geochemical Environmental Assessment of European Lithium Mining and Extraction

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1. Introduction

In the context of mobility decarbonization, lithium (Li) has become indispensable due to its role in Li-ion batteries used in electric vehicles. Despite the anticipated 20-fold increase in demand for Libased batteries by 2050 (Xu et al., 2020), the EU fully relies on major Li producers such as Australia, Chile, and China, creating a high risk of supply disruption. In order to tackle the lack of secure and sustainable access to critical raw materials including Li, the European Critical Raw Materials Act is an essential regulatory framework which aims to ensure 10% of the EU's annual needs for extraction (European Commission, 2023).

In this context, two mines want to start Li production in Europe in 2025, one from the Barroso pegmatite in Portugal and the other from the Rapasaari pegmatite in Finland. Recovery of Li is also envisaged from the Beauvoir (France) and Saint-Austell (UK) rare-metal granites.

The security of Li-supply for Europe is expected to align with its sustainability goals (European Commission, 2023). In general, open-pit mining operations might increase the transfer of potentially harmful elements (PHEs) trapped in minerals into the environment (Monjezi et al., 2009). Waste rocks and tailings produced by mining activities can also pose potential risks to both the environment and human health (Dold, 2008). However, there is limited research on the environmental impacts of Li extraction from hard-rock open-pit facilities (Toupal et al., 2019, Gao et al., 2023, Antao et al., 2024). This study aims to give insights on the environmental impact of European Li extraction from hard-rock deposits by investigating the mobility of potentially harmful elements (PHE) as well as Li in Li-rich ore samples, and in tailings, in relation to waste management.

2. Materials & Methods

The mobility of PHEs in the spodumene-bearing LCT pegmatite from Barroso (Portugal) and lepidolite-bearing granites from Beauvoir (France) and St Austell (United Kingdom) was assessed by standardized leaching tests. A tailing sample resulting from the Li recovery of the Rapasaari pegmatite obtained from pilot studies was also studied. The leached concentrations of metal(loids) resulting from leaching tests were compared to limit threshold values proposed by the European (EN 12457-2, 2002) and US environmental regulations (US EPA, 1992). Leaching was performed on samples with grain size below 200 µm, and at room temperature (ca. 20 °C) in 30 ml Nalgene centrifuge tubes. To evaluate samples representativity and quality control, all tests were performed as duplicates with blanks.

The EN 12457-2 leaching test is used to classify granular waste materials as inert, non-hazardous and hazardous in the EU (EN 12457-2, 2002). The extraction fluid is Ultrapure MQ water. The liquid-to-solid ratio is 10 (1 g of sample per 10 mL of extraction fluid). The tubes were shaken laterally for 24 hrs at 100 rpm and then centrifuged for 10 min at 3200 rpm. The pH of the samples was measured in leachates resulting from this test.

The Toxicity Characteristic Leaching Procedure (TCLP) was also performed. The latter was designed to simulate the worst-case scenario of co-disposal with municipal landfills (US EPA, 1992). A volume of 20 mL extraction fluid #1 (glacial acetic acid with 1 M NaOH; pH 4.9) was added to 1 g of sample (L/S ratio of 20). The tubes were shaken laterally for 18 hours at 100 rpm and then centrifuged for 10 min at 3200 rpm.

After leaching, the solutions were filtered (0.45 µm Chromafil® filters), acidified with HNO_3, and stored at 5°C before analysis. Induced coupled plasma-optical emission spectroscopy (ICP-OES) was used to measure the leached concentrations for Al, As, Ba, Be, Cd, Co, Cr, Cu, Fe, K, Li, Mg, Mn, Na, Nb, Ni, P, Pb, Rb, S, Sn, Sr, Ta, Ti, W, Zn, Zr.

3. Results & Discussion

The results from the EN 12457-2 leaching tests evidence a very low release of PHEs (As, Cr, Cu, Ni and Zn) below 1 mg/kg across all samples (Fig. 1). The leaching of As from the Barroso ore is slightly higher (ca. 2 mg/kg) but remains about 10 times below the limit values (Table 1). The leached concentrations for the PHEs investigated are even below the limit of detection of ICP-OES in the Saint Austell granite sample.

The TCLP results indicate higher release of PHEs, in particular for Cu, Ni and Zn, in comparison with the EN 12457-2 leaching test. This increased mobility can be attributed to the lower pH of the TCLP test and the presence of ligands that facilitate the dissolution of their mineralogical hosts. However, there are no significant differences between the mobility of As and Cr between the two tests, suggesting that their mineralogical hosts are less sensitive to acidic pH and compositional variations of the extraction fluid (Fig. 1). However, their concentrations remain low (< 4 mg/kg) and are compliant with existing regulatory thresholds for As and Cr (Table 1).

Lithium has recently been drawing attention in environmental studies due to the extensive Li mining and the disposal of spent Li batteries (Bolan et al., 2021). However, its toxicity to environment and human health is not well known due to lacking studies regarding Li mobility in ores and tailings from mining areas (Yang et al., 2023).

The mobility of Li was also determined using both EN 12457-2 and TCLP leaching tests (Fig. 2). Lithium is significantly leached from the Beauvoir and Rapasaari samples while it is just above the limit of detection in the Saint Austell and Barroso samples (< 1 mg/kg). The TCLP test (Fig. 2) revealed higher lithium leaching (35 and 25 mg/kg for Beauvoir and Rapasaari, respectively) compared to the EN 12457-2 test (20 and 6 mg/kg).

Table 1. Limit values (mg/kg) for compliance leaching tests using EN 12457-2 and TCLP (NA: non-available)

	EN 12457-2	TCLP
As	25.0	100.0
Cr	70.0	100.0
Cu	100.0	NA
Ni	40.0	NA
Zn	200.0	NA

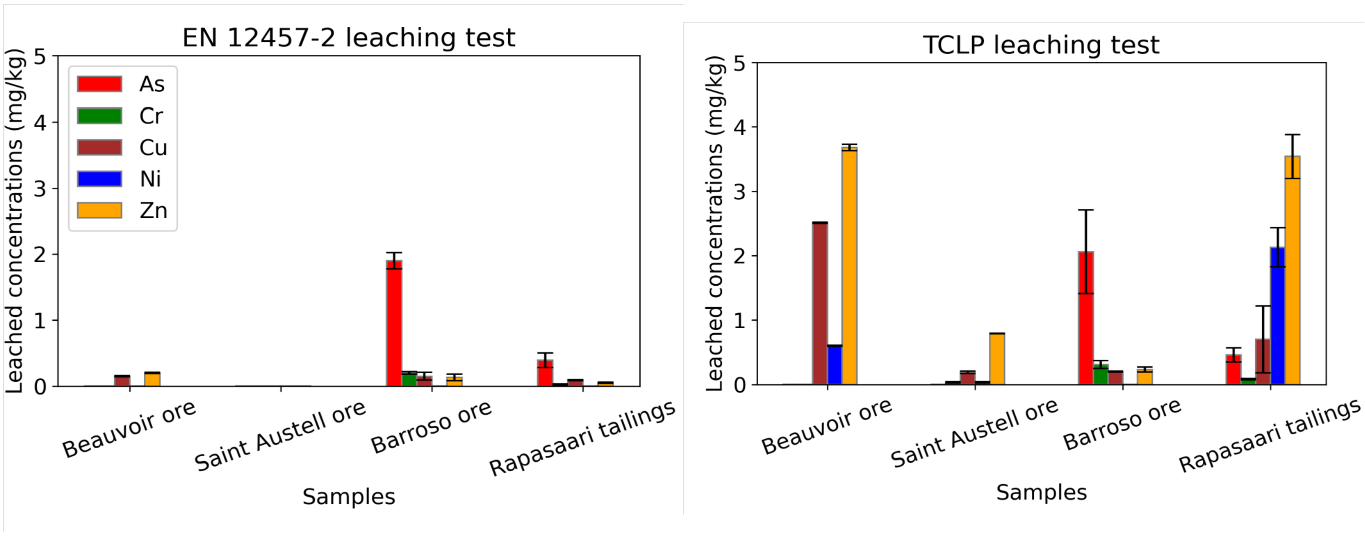

Figure 1. EN 12457-2 and TCLP results in mg/kg for As, Cr, Cu, Ni and Zn on the Beauvoir, St Austell, Barroso ores and the Rapasaari tailing samples. All leached concentrations comply with regulatory limits where applicable.

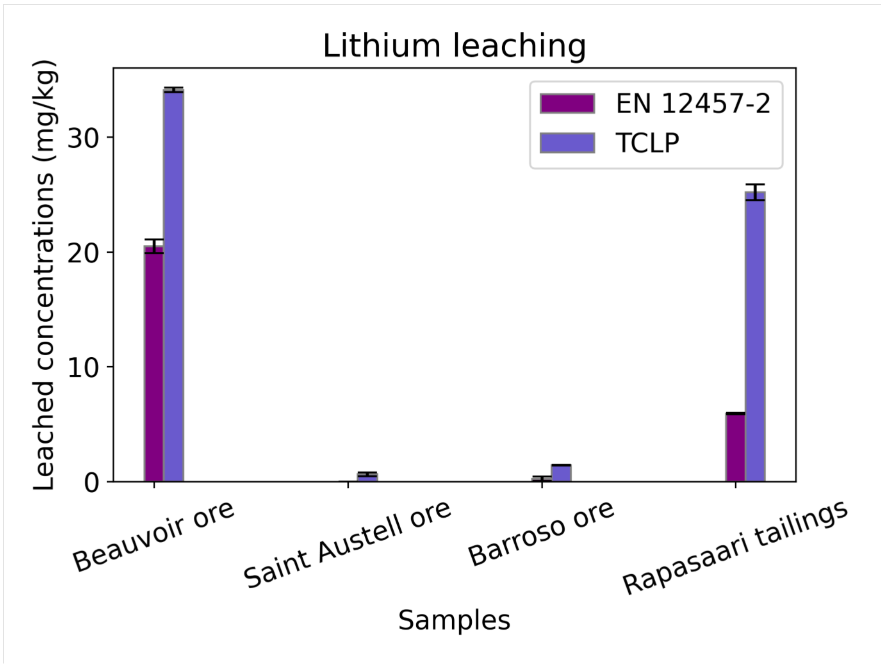

Figure 2. Results from the EN 12457-2 and TCLP leaching tests in mg/kg for Li on the Beauvoir, St Austell, Barroso ores and the Rapasaari tailing samples.

4. Conclusions

We assessed the mobility of PHEs and Li through leaching tests. The mobility of PHEs was found to be low in all the samples examined, indicating their inert nature with regards to waste management. The leaching of Li from ores and tailings at the Beauvoir and Rapasaari site asks for a further evaluation of these materials in terms of waste management and Li-recovery. Further characterization will be conducted to evaluate the bioavailability of PHEs and Li in these materials, in relation to human health risk assessment.

5. Acknowledgments

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6. References

Antão, A.M., Rodrigues, P.M., Rodrigues, R. and Couto, G. (2024). Laboratory weathering studies to evaluate the water quality impact of a lithium mining in Portugal. Environmental Earth Sciences, 83(7): 1-10.

Bolan, N., Hoang, S.A., Tanveer, M., Wang, L., Bolan, S., Sooriyakumar, P. and Rinklebe, J. (2021). From mine to mind and mobiles–Lithium contamination and its risk management. Environmental Pollution. 290: 118067.

Dold, B. (2008). Sustainability in metal mining: from exploration, over processing to mine waste management. Reviews in Environmental Science and bio/technology. 7: 275-285.

EN 12457-2 (2002). Characterisation of waste leaching compliance test for leaching of granular waste materials and sludges—part 2. The European Committee for Standardization (CEN), Brussels.

European Commission (2023a) European Critical Raw Materials Act. In: European Commission - European Commission.

Gao, T.M., Fan, N., Chen, W. and Dai, T. (2023). Lithium extraction from hard rock lithium ores (spodumene, lepidolite, zinnwaldite, petalite): Technology, resources, environment and cost. China Geology, 6(1): 137-153.

Kszos, L.A. and Stewart, A.J. (2003). Review of lithium in the aquatic environment: distribution in the United States, toxicity and case example of groundwater contamination. Ecotoxicology. 12: 439-447.

Monjezi, M., Shahriar, K., Dehghani, H. and Samimi Namin, F. (2009). Environmental impact assessment of open pit mining in Iran. Environmental Geology. 58: 205-216.

Toupal, J., Vann, D.R., Zhu, C. and Gieré, R. (2022). Geochemistry of surface waters around four hard-rock lithium deposits in Central Europe. Journ. of Geochemical Exploration. 234: 106937.

US EPA (1992). Method 1311 Toxicity Characteristic Leaching Procedure. Report). Washington, DC: U.S. Environmental Protection Agency (EPA). July 1992. Part of "Test Methods for evaluating Solid Waste, Physical/Chemical Methods." Documentaliste SW-846.

Xu, C., Dai, Q., Gaines, L., Hu, M., Tukker, A. and Steubing, B. (2020). Future material demand for automotive lithium-based batteries. Communications Materials. 1(1): 99

Yang, X., Wen, H., Lin, Y., Zhang, H., Liu, Y., Fu, J., Liu, Q. and Jiang, G. (2023). Emerging research needs for characterizing the risks of global lithium pollution under carbon neutrality strategies. Environmental Science & Technology. 57(13): 5103-510

Integrating Innovative Lithium Resources Recover Technologies: Forging a Path to a Net Zero Future

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Keywords: *Sustainable Mining; Sustainable Assessment; Resource Efficiency; Net Zero*

Abstract

As we progress through the energy and digital twin-transition, mineral resources, particularly critical raw materials (CRMs), are playing an increasingly crucial role in this fast-societal transformation. Building upon the latest targets outlined in the CRMs Act from March 2023, which set even higher EU 2030 benchmarks for strategic raw materials at extraction, recovery, and recycling (EC, 2023). This study seizes the opportunity to further address these benchmarks by introducing sustainable practices, together with sustainable assessments. This work highlights the contribution of Politecnico di Torino to international projects, particularly focusing on its involvement in the Horizon Europe project METALLICO (2024). The latter aims to introduce innovative technologies and more sustainable pathways in the mineral recovery life cycle. The methodological approach adopted consider and explore current challenges in the mining industry in terms of eco-friendly practices and process circularity (Tuusjarvi et al, 2012). This study showcases sustainable assessment of mineral recovery case study of battery minerals and introduces approaches to tackle issues associated with environmental assessment, aiming to provide a more consistent evaluation of environmental impacts throughout the life stages of mineral recovery technologies. Through sustainable assessments, we demonstrate how lab-scale recovery technologies can effectively reduce environmental burdens, optimize recovery, and minimize waste and emissions (COOL process) (Mende et al, 2023). Future research foresees the upscaling of these innovative battery mineral technologies into larger industrial production towards net-zero emissions and resource efficiency conceptual approaches.

References

European Commission (2023) Study on the Critical Raw Materials for the EU 2023 – Final Report.

Mende, R., Kaiser, D., Pavón, S. and Bertau, M. (2023). The COOL Process: A Holistic Approach Towards Lithium Recycling. Waste and Biomass Valorization. 14: 3027–3042

Metallico (2024) Demonstration of battery metals recovery from primary and secondary resources through a sustainable processing methodology. GA 101091682. https://metallico-project.eu/

Tuusjarvi, M., Vuori, S. and Maenp, I. (2012). Metal Mining and Environmental Assessments: A New Approach to Allocation. Journal of Industrial Ecology. 16(5): 2012.

Decarbonisation

Digitalisation and Technological Innovations Towards Energy-Efficient Quarries

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1. Introduction

As an energy-intensive industry, energy efficiency has been a long-standing concern for mining companies. It not only represents a substantial share of the operating expenditures (OPEX) but also contributes significantly to greenhouse gas emissions. Addressing this issue is a transversal challenge in the industry, especially for the aggregate sector, as it represents the largest share of minerals used globally (OECD, 2019).

Accordingly, enhancing the energy efficiency of quarries is one of the main goals of the DigiEcoQuarry (DEQ) project, a collaboration initiative between industry and academia under the umbrella of the EU Horizon 2020 programme. The project targets digitalising quarries in Europe to leverage their profitability, monitor and mitigate their environmental impact, improve safety conditions, and facilitate social understanding with the community.

In this context, this paper presents the current progress of the project regarding energy efficiency. It includes (i) an overview of the energy consumption at the pilot sites of the project, (ii) an analysis of renewable energy (RE) consumption and generation in the aggregate sector, (iii) an overview of the technologies and systems implemented, and (iv) the assessment of the overall impact of these solutions.

2. Materials & Methods

The solutions developed in the project are deployed and tested in five pilot sites: Lisbon (Portugal), Madrid (Spain), Mammendorf (Germany), Milan (Italy), and Toulouse (France). These operations differ in their products, extraction methods, and other on-site conditions, providing a representative sample of the quarrying sector.

The outcomes presented in this document are based on the following methods:

i. Relevant indicators for the characterisation of energy consumption in the pilot sites.
ii. Literature and case studies review to identify critical factors affecting consumption and generation of RE in the aggregate sector.
iii. Overview of the technologies developed in the project that aim to improve energy efficiency along the quarrying value chain.
iv. Estimation of the overall potential impact on energy efficiency, with a focus on the expected fuel and electricity consumption reductions and also considering the electricity consumed by the ICT tools involved.

3. Results & Discussion

3.1 *Characterisation of the energy consumption at the pilot sites*

Figure 1 presents leading energy-related indicators for the pilot sites in the period 2021-2023 (mean values marked with X). On the one hand, fuel intensity is significantly influenced by the operation's layout, i.e., distances between the loading points and crusher, as well as waste/overburden piles. This can translate into longer cycle times and, therefore, higher fuel consumption per unit of material. On the other hand, electricity intensity is affected by several factors, mainly the rock type and hardness and the presence of fines, i.e., clay. Finally, and as anticipated, the average share of energy in the pilot sites' monthly OPEX is 31%, with maximums close to 50%.

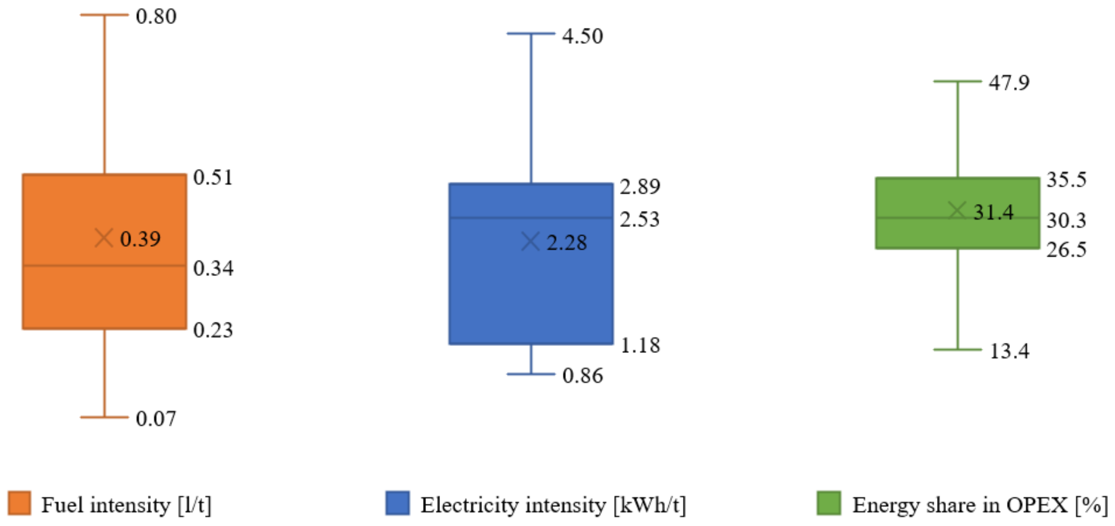

Figure 1. Boxplots showing relevant energy-related indicators for the pilot sites in the period 2021-2023

3.2 *Renewable energy (RE) in the aggregate sector*

RE technologies are increasingly being incorporated by the mining industry, driven by the need to reduce its environmental footprint but also as a means to minimise costs. The declining costs of RE, opposite to rising costs for traditional sources, are boosting the economic viability of renewables for mining operations (Zharan & Bongaerts, 2017).

Based on relevant literature, reports from companies and competent agencies, case studies from recent years, and the experience of the pilot sites in the project, a series of requirements have been identified as the main enabling drivers for implementing a RE project by an aggregate producer. These are investment capabilities, load profile of the energy consumption, land availability, life of mine (LOM), specialised personnel and knowledge, and energy storage requirements. Table 1 states the conditions at a given operation that are compatible with each RE, providing guidelines for a company evaluating investing in further RE adoption.

3.3 *DEQ solutions aiming to enhance energy efficiency*

The project addresses each stage of the quarrying value chain by developing novel technologies and smart monitoring systems. Additionally, the project includes the development of a digital platform that integrates the data generated by the innovative tools, allowing further analyses and insights.

Table 1. Requirements and compatibility of RE sources.

Renewable energy source	Investment capabilities			Load profile			Land availability			LOM			Specialised personnel and knowledge			Energy storage	
	High	Medium	Low	Continuous	Discontinuous	Daytime-focused	High	Medium	Low	<10 years	10-25 years	>25 years	High	Medium	Low	Yes	No
Solar (photovoltaic)	✓	✓	✓			✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓
Wind energy	✓	✓	✓		✓		✓	✓			✓	✓	✓	✓		✓	
Hydropower	✓			✓			✓	✓	✓			✓	✓			✓	✓
Geothermal	✓			✓			✓	✓				✓	✓			✓	✓
Concentrated Solar Power (CSP)	✓					✓	✓				✓	✓	✓			✓	
Power Purchasing Agreement (PPA)	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓

The solutions are different in nature. While some correspond to production machinery, e.g., a new drill rig or a hybrid mobile crusher, others are smart sensor monitoring systems and supporting software. Likewise, their effect on reducing energy consumption is materialised through distinct mechanisms: a new machine can be superior to traditional equipment regarding energy efficiency, or a system can provide tools for optimising the operation and, in consequence, reducing energy consumption.

Table 2 summarises these solutions and their characteristics. In total, eight of the technologies developed in the project have a direct impact on energy efficiency. Additionally, two cross-sectional analyses are conducted to further improve the operations.

These systems have the potential to enhance energy efficiency both locally, i.e., at a specific unit process, and in linked processes or even the overall operation. Moreover, these developments also contribute to enhancing other aspects of quarrying operations, such as productivity, safety, environmental performance, and social acceptance.

3.4 Impact on energy efficiency

In addition to the energy savings that could be achieved by implementing the DEQ solutions, electricity attributable to the information and communication technologies (ICTs) involved in the project must also be considered. Worldwide, the ICT sector has experienced an important growth over the past decade: while by 2012, it was estimated to represent approximately 3.9% of the electricity consumed globally (van Heddeghem et al., 2014), recent estimations indicate a share closer to 8% of the total (Jha et al., 2023).

The ICT energy consumption in the project, considering the application in one quarry, was estimated based on (i) the total data transferred, (ii) data storage requirements, and (iii) computing tasks (Andrae, 2020; Aslan et al., 2018). The results suggest that the total electricity attributable to the digital services in the project, though not negligible, is minor in the context of the operation, equivalent to less than 0.1% of the total consumed by a quarry on a yearly basis.

Table 2. Overview of DEQ solutions towards energy consumption reduction.

			Expected consumption reduction		Other positive impacts			
Process in the value chain	**Type**	**Scope of impact on energy efficiency**	**Fuel**	**Electricity**	**Productivity**	**Safety**	**Environment**	**Social acceptance**
Drilling	Drill rig	Local	16%	N/A	✓	✓	✓	✓
Blasting	Smart blasting	Local & downstream	5-10% (digging)	2-5% (crushing)	✓	✓	✓	✓
Material handling	Hybrid mobile crusher	Local	15%	N/A	✓	✓	✓	✓
	Fleet monitoring systems (2)	Local	5-10%	N/A	✓	✓	✓	✓
Processing	Plant optimisation systems (2)	Local	N/A	10-15%	✓	✓	✓	✓
	Digital twin	Local	N/A	TBD	✓	✓	✓	
Cross-sectional analysis	Drill-to-mill analysis	Overall	TBD	TBD	✓	✓	✓	
	Machine learning methods for fuel consumption	Local	TBD	TBD	✓		✓	✓

Finally, two scenarios, expected and optimistic, were defined based on the potential achievements of the DEQ solutions described in Table 2. For an integral evaluation, the impact has been measured in tonnes of CO_2 emissions by using a factor of 2.68 kg CO_2/l for fuel consumption (diesel) and country-specific supplier mix factors for electricity consumption (AIB, 2023).

The estimation indicates that CO_2 emissions related to energy consumption could be reduced by 5% in the expected scenario and a potential of almost 12% in the more optimistic outcomes. Thus, by far overcompensating the extra energy needed for the ICT services.

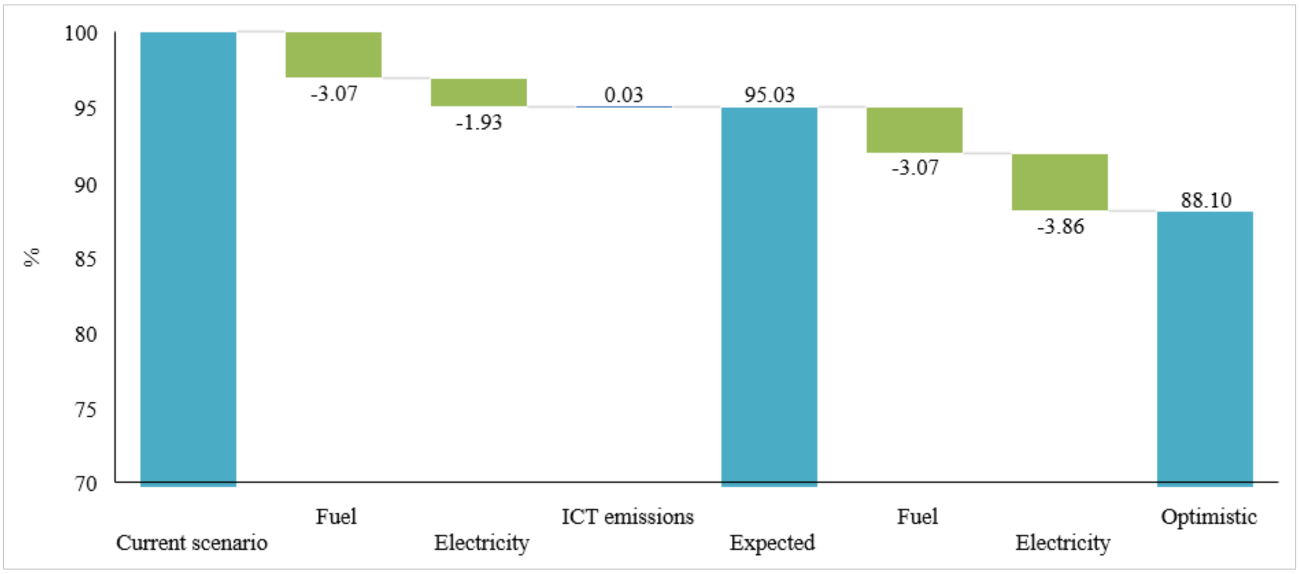

Figure 2. Potential impact on energy-related CO_2 emissions from the implementation of DEQ

4. Conclusions

The DEQ project addresses energy efficiency comprehensively. The tasks involve understanding the requirements for different types of quarries, analysing the limitations and enabling factors for higher renewable energy adoption in the aggregate sector, and developing new technologies and systems to reduce consumption along the value chain.

The installation of these tools has been the major focus. Individually and collectively, these solutions show great potential to enhance energy efficiency in all unit processes of the quarrying productive cycle. Current estimations indicate that a quarry might be able to reduce its annual CO_2 energy-related emissions considerably by implementing these systems. Moreover, expected energy savings far exceed the electricity consumption associated with the ICT component of the project, proving the effectiveness of the tools developed.

The remaining stage of the project is focused on successfully completing the deployment and testing of the different systems and the cross-sectional analysis based on the data generated.

It is expected that the model developed in DEQ can be replicated in quarries across Europe, benefiting the sector and increasing its contribution to society as a sustainable and profitable economic activity.

5. Acknowledgements

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6. References

AIB (2023). European Residual Mixes: Results of the calculation of Residual Mixes for the calendar year 2022.

Andrae, A. (2020). New perspectives on internet electricity use in 2030. Engineering and Applied Science Letter. 3(2): 19-31.

Aslan, J., Mayers, K., Koomey, J. G. and France, C. (2018). Electricity intensity of internet data transmission: Untangling the estimates. Journal of industrial ecology. 22(4): 785-798.

OECD (2019). Global Material Resources Outlook to 2060 Economic Drivers and Environmental Consequences. OECD publishing.

Jha, A. K. R., Andrae, A. S. G. and Mainali, B. (2023). Comparison of Methods for Calculating Indirect Upstream Carbon Emissions from Information and Communication Technology Manufacturing. WSEAS Transactions on Environment and Development. 19: 1045–1057.

Van Heddeghem, W., Lambert, S., Lannoo, B., Colle, D., Pickavet, M. and Demeester, P. (2014). Trends in worldwide ICT electricity consumption from 2007 to 2012. Computer Communications. 50: 64-76.

Zharan, K. and Bongaerts, J. C. (2017). Decision-making on the integration of renewable energy in the mining industry: A case studies analysis, a cost analysis and a SWOT analysis. Journal of Sustainable Mining. 16(4): 162-170.

Decarbonising Strategic Mineral Supply Chains: Open-Source Tools for Assessment for Renewables and Hydrogen Integration

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Keywords: Technoeconomic Analysis, Opensource Tool, Green Minerals, Net-zero, Green Steel, Green Copper.

Abstract

As the global demand for green strategic minerals increases, resource rich nations are facing pressure to reduce greenhouse gas emissions of their mineral supply chains or risk a decline in export market share (IEA, 2022). To meet such decarbonisation targets, both renewable energy and hydrogen (and their derivatives) integration is acknowledged to be the key levers. Given that the vast majority of these strategic minerals (such as Fe, Cu, Li, Co, Ni, etc.) will play a vital role in development and deployment of further renewable energy technologies (electric vehicles, in wind turbines, photovoltaics, electrolysers), it is imperative that the technological and economic aspects of renewable integration to otherwise hard-to-abate mineral sector is explored through open-transparency.

To address this research and market demand, open source technoeconomic tools have been developed to aid with policymakers and relevant stakeholders in the costs, carbon emissions and technological requirements necessary to develop and implement green mineral supply chains for the export of green iron & steel and copper, and to be further expanded to other strategic minerals. The framework for the tool is presented in Figure 1.

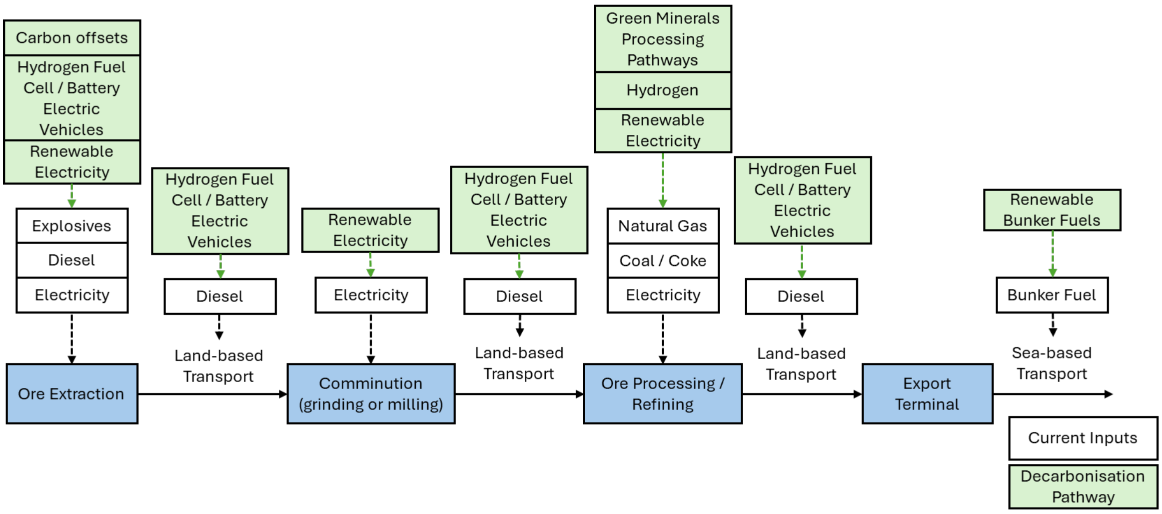

Figure 1. Technoeconomic Framework for Renewable Integration into Green Mineral Supply Chain.

The models have been applied for an Australian case study, given the significance of mining industry in the country (Centre for Policy Development, 2023) but have been developed in a in a way that enables them for applications anywhere across the globe.

References

Centre for Policy Development. (2023). Green Gold. A Strategy to Kickstart Australia's Renewable Energy Future.

International Energy Agency (2022). The Role of Critical World Energy Outlook Special Report Minerals in Clean Energy Transitions.

Global Iron and Steel Decarbonisation Roadmaps: Near-Zero by 2050

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Keywords: Near-zero steel; decarbonisation roadmap; net-zero 2050; iron ore mining; low carbon transition; sustainability gaps

Abstract

A valuable depth of knowledge has developed in the academic and grey literature as more voices have joined the conversation on decarbonising heavy industry. This paper analyses the current state of research through a critical review of global iron and steel decarbonisation roadmaps to 2050. The consensus among scenarios and modelled pathways is that the sector will achieve near-zero emissions, falling short of net-zero targets by around 10%.

The key barriers identified include the availability of recycled scrap, limited availability of high-grade iron ore, de-risking technology investment, uncertain demand and cost gap, the availability, affordability, and reliability of renewable energy and hydrogen, skilled workforce shortages, weak policy signals, and the lack of certification and regulation for fair competition.

The roadmaps focus on breakthrough technology pathways for steel producers, while emphasising the need for consistent improvements to yield, energy efficiency, secondary steelmaking, and carbon capture solutions. However, significant sustainability gaps exist in the largely carbon dioxide (CO_2) focused plans. Significant doubt prevails for the efficacy of carbon capture and storage, while discussion of indirect emissions from the raw mineral extraction, transport, use, and end-of-life stages of steelmaking are limited.

To achieve a just transition, greater attention is needed to address the social licence to operate and broader environmental impacts including the production of waste and non-CO_2 emissions. The de-coupling of iron and steelmaking presents an opportunity for strategic international collaboration and shared responsibility in the development of a sustainable iron and steel value chain.

Social License to Operate

The Importance of Techno-Economic Assessment (TEA) in Mining, Metallurgical and Waste Valorisation Projects in the Era of Green Transition

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Keywords: metallurgical processes; public acceptance; geochemical valorization; alkali activated materials (AAMs); simulation and optimization

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Abstract

The tool of Techno-economic Assessment (TEA) holds a key role towards optimization and decision-making within complex mining and metallurgical processes. In conjunction to life cycle analysis (LCA), TEA can build up a systematic integrated strategy that will evaluate, both qualitatively and quantitatively, the economic & environmental impacts of processes across their entire life cycle; from mining to added-value product production and final disposal.

The present paper attempts to underline the importance of TEA by presenting two case studies that are initially evaluated:

(i) the High Pressure Acid Leaching (HPAL) of laterites (nickel/cobalt oxide ores) for the production of Mixed Hydroxide Precipitates (MHP) and
(ii) (ii) the alkali activation of metallurgical slags for the production of alkali activated materials (AAMs).

The HPAL is one of the main processes used for the treatment of laterites and the production of MHP. Despite the development of several other specific processes since its first commercialization in 1961, HPAL generally involves pressure leaching of limonitic ores in autoclaves with the use of sulphuric acid, followed by a counter-current decantation (CCD) circuit between two progressive neutralization steps with the use of limestone; it is mentioned that the pressure leaching of high magnesium ores (saprolites) in autoclaves results in the generation of scale and in this case atmosphere leaching may be considered (Kontopoulos & Komnitsas, 1988). Following neutralization, the process enables the recovery of MHP via precipitation with magnesium oxide prior to scavenger precipitation and manganese removal by further neutralization with lime (Whittington & Muir, 2008). Owing to its ability to leach nickel relatively quickly and with reduced acid consumption due to its hydrolytic regeneration, HPAL projects attracted in the last decade investments for about 20 billion USD, especially in Asia and Southwest Pacific.

Alkali activation of tailings and slags is an innovative approach to address both environmental and economic challenges associated with metallurgical waste management and valorisation. The by-products of ore processing (tailings) in mining operations are typically stored in tailings dams, possessing environmental risks such as leaching of potentially hazardous elements (PHEs) and the catastrophic dam failures (Komnitsas et al., 2023). On the other hand, slags may be disposed on land or under water, mainly in the sea, and may also cause environmental problems due to solubilization of PHEs under varying environmental conditions. Alkali activation offers a sustainable solution for utilizing these streams as a resource rather than a waste (Komnitsas et al, 2020). To this end, the present paper presents a preliminary study that involves the following (Fig.1): a) state-of-the-art analysis in order to identify gaps that need to be filled in with advanced simulation and techno-economic analysis, b) set-up of a basic flowchart for the alkali activation of fayalitic slags obtained from pyro-processing of raw materials and c) mapping of input and output streams in order to identify the economic potential of the proposed process. Throughout the TEA set-up, alternative combinations that will retrofit the process simulation and optimization towards the most advanced pathway will be investigated (Granata et al., 2022)

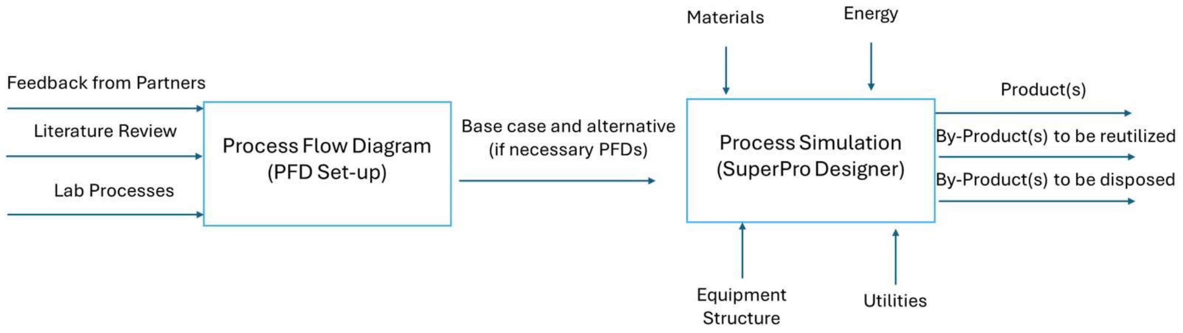

Figure 1. Process simulation framework

This holistic TEA approach helps in identifying opportunities for improving resource efficiency and reducing environmental footprint, enhancing at the same time the social acceptance in mining, metallurgical and waste valorisarion projects.

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References

Whittington, B.I. and Muir, D. (2008). Pressure Acid Leaching of Nickel Laterites: A Review. Mineral Processing and Extractive Metallurgy Review. 21(6): 527-599.

Granata, G., Altimari, P., Pagnanelli, F. and De Greef, J. (2022). Recycling of solar photovoltaic panels: Techno-economic assessment in waste management perspective. Journal of Cleaner Production. 363: 132384.

Kontopoulos, K. and Komnitsas, K. (1988). Sulphuric acid pressure leaching of low-grade Greek laterites. In the Proceedings of the 1st International Symposium on Hydrometallurgy, Zheng Yulian, Xu Jiazhong eds., 12-15 Oct., Beijing, China, Pergamon Press, Oxford 1988, 140- 144.

Komnitsas, K., Yurramendi, L., Bartzas, G., Karmali, V. and Petrakis, E. (2020). Factors affecting co- valorization of fayalitic and ferronickel slags for the production of alkali activated materials. Science of the Total Environment. 721: 137753.

Komnitsas, K., Petrakis, E. and Bartzas, G. (2023). A novel and greener sequential column leaching approach for the treatment of two different Greek laterites. Science of the Total Environment. 854: 158748.

Public Acceptance and Responsible Mining Towards Energy Transition

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Keywords: Critical Raw Materials (CRM), Sustainable Development Goals (SDGs),

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Abstract

Critical Raw Materials are essential in the modern-day economy, for digitalization, renewable energy technologies, electric vehicles and long-duration energy storage (LDES) so that our society meets the targets of Sustainable Development Goals (SDGs) (KU Leuven, 2023).

The European Commission's (EC) Critical Raw Materials Act (CRMA) sets multiple benchmarks for dependency on just a few third countries for many of its strategic/critical raw materials (CRMs). Member States are supported to secure a resilient, sustainable and ethical supply of CRMs for the transition to a net-zero economy.

For example, Europe is almost 100% reliant on imports of Li for the Li-ion batteries that are central to decarbonising the energy and mobility sectors. A small fraction of European needs can be covered from recycling of End-of-Life (EoL) car batteries, but primary supply still must cover more than 90% of the Li demand. On the other hand, Europe hosts 27 Li hard-rock (pegmatite & Rare-Metal Granite) deposits, representing vast lithium resources (8.8–21.7 Mt Li2O) (Gourcerol et al., 2019; Bruno & Fiore, 2024).

Furthermore, the European Commission identified vanadium (V) as a CRM for strategic technologies and sectors in 2017. Europe has a multitude of unexploited, low-grade V-bearing titanomagnetite deposits in Finland, Sweden, Greenland, Norway, Poland, and Ukraine. Most of these deposits have a complex "spiderweb-like" mineral assemblage and without the use of selective blasting and fragmentation, as well as pre-concentration technologies to separate the Ti-rich ilmenite from the V-bearing magnetite, are not economically viable. As a result, despite the potential recovery of V from steel slag, the targets of the CRMA for more than 10% domestic extraction of V and Ti cannot be met.

It is evident that the goals of the Paris Climate Agreement (PCA) to reduce carbon without more mining and the use of critical minerals cannot be met. However, the European potential to explore and mine its resources and produce strategic and critical elements remains largely untouched, partly due to a reluctant attitude towards mining in several European countries. This attitude is also supported by the fact that some multinational companies involved in mining of CRMs also mine fossil fuels such as coal. On the other hand, it has to be underlined that the leading European companies follow in most cases the principles of responsible exploration, mining, smelting and recycling.

Another aspect that needs to be highlighted is related to the long processes required for obtaining exploration permits. It is known that in most European countries the average lead time from discovery of mineral resources to production often exceeds 15 years.

The major barrier to overcome this negative attitude to exploration and mining is the industry's association with accidents and ecological damage, mainly due to tailings dam failure, mine collapse and CO2 emissions. More recently, there are accusations that in Indonesia, the country with the largest nickel reserves in which nickel production has nearly tripled since 2020, protected forests in the Sulawesi region are damaged and the livelihoods of the indigenous Bajau people are endangered. Furthermore, other accusations are made in western Australia that during the mining of iron ores part of the ancient Juukan Gorge caves in aboriginal sites was damaged.

Thus, even though many stakeholders agree on the need for more mining of critical / strategic resources, several people are not happy with an operating mine in their backyard.

The social license to operate (SLO) / public acceptance (PA) is an informal social contract first developed in the 1990s to improve the relations between the mining industry and the society. A successful social contract is a prerequisite for the implementation of an exploration / mining project. Most of the disputes among companies and various stakeholders occur as a result of conflicting land uses or due to an advanced risk for affecting the environment, the communities and the ecosystems in the area of concern. Furthermore, estimates indicate that around 50% of critical material resources are located near indigenous people's land (Eerola 2021; Eerola 2022).

The success of an SLO / PA depends on the degree in which the gap among the views of the mining companies and various stakeholders, including the general public, is bridged. The last years, mining companies have taken initiatives to improve their performance and image and to promote stakeholder engagement and company–community relationships. However, a crucial aspect is that the mining industry needs to admit its past faults and increase transparency. So far, more often the positive economic impacts associated with mining of CRMs, including more jobs and better economic prospects, are highlighted by the industry, but this approach may not be sufficient to reverse the negative attitude (Komnitsas, 2020).

Other important aspects towards SLO / PA include the use of new low-impact mineral exploration and mining technologies, involving also artificial intelligence (AI), that address health, safety and environmental issues and have competitive advantages over the traditional ones. These technologies may involve among others closed circuit drilling, deep-penetrating electro-magnetic survey, muography and the use of drones (Eerola & Komnitsas, 2023).

It is strongly believed that the PA will be improved if responsible and reliable mining principles are planned so that (i) environmental impacts, associated with many dams hosting beneficiation tailings in several countries are minimized, (ii) risks associated with loss of biodiversity are reduced, (iii) water management in the broader mining industry is optimized and (iv) a breakthrough technological innovation is promoted/generated in all related aspects involving exploration, mining, beneficiation, metallurgy and waste valorization.

This proposed approach is in line with the United Nations Economic Commission for Europe (UNECE) Framework for CRMs that involves among others the establishment of a comprehensive Socio-Environmental-Economic Contract to Operate, integrating impacts on societies and communities, the need for a just transition, climate change mitigation and adaptation, and environmental stewardship (UNECE, 2024).

The present paper attempts to highlight all important factors and actions that need to be taken in order to update regulations and standards and apply good practices for responsible mining, in order to meet the goals of the PCA and improve the relations and the trust between the mining industry, the society and all involved stakeholders.

Acknowledgments

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References

Gourcerol, B., Gloaguen, E., Melleton, J., Tuduri, J. and Galiegue, X. (2019). Re-assessing the European lithium resource potential – A review of hard-rock resources and metallogeny. Ore Geology Reviews. 109: 494-519.

Eerola, T. (2022). Corporate conduct, commodity and place: Ongoing mining and mineral exploration disputes in Finland and their implications for the social license to operate. Resources Policy. 76: 102568.

Eerola, T. (2021). New low-impact mineral exploration technologies and the social license to explore: Insights from corporate websites in Finland. Cleaner Environmental Systems. 3: 100059.

Komnitsas, K. (2020). Social license to operate in mining: Present views and future trends. Resources. 9(6): 79.

Bruno, M. and Fiore, S. (2024). Review of lithium-ion batteries' supply-chain in Europe: Material flow analysis and environmental assessment. Journal of Environmental Management. 358: 120758.

Eerola, T. and Komnitsas, K. (2023). Preliminary Assessment of Social License to Operate (SLO) and Corporate Communication in Four European Lithium Projects. Material Proceedings. 15(1): 35.

SIM² KU Leuven / Storyrunner (2023). Europe's Mining Renaissance, a Catalyst for Climate Neutrality. Retrieved from: https://kuleuven.sim2.be/#uael-video-gallery-b38c2db-2

UNECE (2024). Critical Raw Materials. Retrieved 28 April 2024 from: https://unece.org/unece-and-sdgs/critical-raw-materials

Local Community Procurement Program (LCPP): Effective Approach to Inclusion in the Supply Chain

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1. Introduction

Mineral exploration and subsequent mining operations initiate a delicate relationship between corporate entities and local communities, shaping socio-economic dynamics throughout the project lifecycle (Henisz, 2017). Within this intricate framework, the importance of inclusive supply chains becomes increasingly evident. This paper examines the critical role of local procurement practices in fostering stakeholder engagement, community inclusion, and enhanced transparency (Warner, 2017), particularly through the lens of the Local Community Procurement Program™ (LCPP).

As mineral exploration projects progress from initial phases to mining construction and operation, opportunities for engagement with local communities multiply, yielding tangible benefits for both parties involved. However, the effectiveness of these engagements' hinges upon comprehensive project development planning, integrating local procurement and workforce inclusion as strategic imperatives. The resilience of such planning processes is underscored by their capacity-building efforts, which extend beyond immediate challenges to leave a lasting positive legacy in regions with limited opportunities (IFC, 2011).

An examination of trade dynamics across the supply chain reveals its dual nature – stimulating collaboration and innovation while carrying inherent social and operational risks. Local communities, aspiring for sustainable development, often face challenges navigating unfamiliar standards in a technical and competitive environment (IFC, 2011). It is within this context that the LCPP emerges as a transformative mechanism, actively developing local capacities through supplier engagement, fostering collaboration, mitigating risks, and contributing to social development.

Through case studies showcasing the integration of local procurement in mineral exploration projects in Ecuador, this paper exemplifies the synergy between understanding local capacities, innovating procurement processes, and building trust. Overcoming engagement obstacles drives project success and underscores the mineral industry's pivotal role in promoting inclusion and participation, thus contributing to global social development (ICMM, 2012).

In synthesizing these insights, this paper aims to underscore the transformative potential of the LCPP in fostering inclusive supply chains and promoting sustainable socio-economic development within mining communities.

2. Materials and Methods

The challenge for many local businesses is that they do not meet the pre-qualification criteria of large procuring entities in their region, often excluding them from the bidding process (Warner, 2017). This exclusion frequently results in conflict between local communities and large players, particularly in the extractives industries (IFC, 2011).

To address this, the LCPP model centers on a four-pillar approach to enabling local communities to enter private or public sector supply chains. It also aims to help small, local businesses become qualified suppliers and gain access to the supply networks of larger organizations. Each pillar can be customized to meet both the needs of the communities in a company's area of influence and the operational needs of a big organization, achieving a balance between community and business development.

The four pillars of LCPP consist of:

Pillar 1 – dialogue with stakeholders: The program starts with engagement with communities, local industries, governments, and the private sector, to achieve understanding of each party's needs and establish transparency within the process. It identifies industries that can serve as job creators for communities, but that will also provide a sustainable livelihood for the community beyond the project lifecycle. The procuring entity is responsible for the wellbeing of the communities in its direct area of influence, the physical and natural environment that its operations impact, and its employees (IFC, 2011). Throughout the program's implementation, it continues to work with the procuring sponsor and local community members to ensure the collaboration and support of everyone involved, and their expectations are met.

Pillar 2 – building capacity: The program then focuses on transferring technical knowledge to participants to build their capacity in areas where industry demand and market opportunities have been identified (IFC, 2007). The training is customized to ensure all participants complete the program successfully, regardless of their social status and knowledge level.

Pillar 3 – support to access the supply chain: Beyond technical training, the program involves educating participants about how to access the local supply chain and compete successfully in the procurement bidding process. This way, the program creates sustainable change.

Pillar 4 – ongoing support: The program provides ongoing coaching, evaluation, and training of community participants, to ensure their continuous development. This way, local communities and small businesses are responsible for helping stimulate the local economy by being competitive, creating new jobs, securing access to local market opportunities, and providing required goods and services. Local governments and agencies are encouraged to support the development of local businesses, and industry associations are brought in to help promote production and secure opportunities for their members (MAC, 2024).

3. Results and Discussion

The Local Community Procurement Program (LCPP) is intended to be adaptable to meet the requirements of diverse industries and communities. The LCPP has achieved notable success in Ecuador, and it is currently involved in a significant mining initiative in Mexico.

3.1. Case study: LCPP in Ecuador

In August 2012, the LCPP was implemented as a pilot project in a mineral extraction project to strengthen the local supply chain and empower communities within the direct area of influence (DAI).

Prior to implementation, a social assessment identified local capacities and challenges, and it was identified that food processing/catering could be a potential field to collaborate with local communities and members. This finding enabling the design of customized training modules for local communities on food management, hygiene, and small business/supplier management.

The LCPP was well-received, with 18 of 19 participants attending at least 75% of sessions, leading to six local small businesses becoming food suppliers. The project's deep understanding of the local context, including the supply chain and socio-economic conditions, allowed tailoring the LCPP to meet demands. Integrating local capacity building enhanced the sustainability and resilience of food processing operations.

This case highlights the importance of a localized approach that addresses unique community needs through customized interventions. The successful LCPP pilot demonstrates the potential for local capacity building to improve development project impact.

3.2 Promoting local capacity building and conflict mitigation through local procurement

By employing the LCPP model, the Ecuadorian project was able to maximize efficiencies in the sponsor's supply chain and procurement process by securing local content, while at the same time developing the existing capacity of local communities and businesses to meet industry standards and demands. In this way, it acts as a tool for conflict mitigation between the private sector and communities by promoting economic inclusion and helping to stimulate community development (ICMM, 2012).

A win-win situation: The program encourages open dialogue, multi-stakeholder collaboration, and transparency (ICMM, 2012). Local suppliers are able to develop their capacity to satisfy a procuring organization’s demands and to meet industry and market standards (Warner, 2017). They develop sustainable skills while helping clients maximize project quality and productivity, avoid costly delays, and reduce administrative costs associated with the procurement process (FITT, 2008).

Strengthening the supply chain: By drawing on local skills and resources, the program helps maximize productivity and quality in the supply chain. It also supports the creation of environmentally sustainable jobs and promotes agriculture and production (Roseland, 1992).

Social and economic sustainability: Participants gain the skills to continue developing themselves and identify opportunities in other markets. The program is specifically designed to avoid dependency on the employment opportunities and social programs provided by the immediate project on which it is based (IFC, 2007). It transfers necessary skills and capacity to small and medium-sized enterprises (ICMM, 2022), ensuring that they adhere to industry standards so that procurement managers can hire them. Thus, local requirements are met, maximizing productivity in the supply chain.

A ripple effect: In Ecuador, participants took the initiative and shared their learning in good hygiene and nutrition practices with their families, helping to improve health in the community.

3.3 Lessons from Ecuador: Critical elements for effective local content and procurement

The key drivers behind the success of the LCPP in Ecuador included several critical elements for effective implementation at the local level:

Gain communities’ trust: Promoting local procurement can help prevent conflict between communities and the private sector. It’s important to enable communities to identify their competencies and set realistic expectations around their involvement in a project (ICMM, 2022). If local talent is integrated into the supply chain, providing communities with meaningful opportunities, they feel engaged in the process, which helps the sponsor to build strong community relations, secure the social license to operate, and avoid conflict. The Ecuador program overcame communities’ initial hesitation – due to previous negative experiences with extractive companies – through meetings, informal visits, and community observation. This meant realistic expectations were established and then met, gaining people's trust, and securing the social license to operate.

Include vulnerable groups: To maximize the social impact of a community procurement program, it's important to include vulnerable groups, transferring knowledge and skills effectively to women, Indigenous Peoples, elderlies, anyone without education, and youth (United Nations, 2009). The program empowers the community by leaving knowledge in their hands and acts in support of dignified and sustainable development. It also helps small local businesses understand and comply with human and labor rights and is designed to meet global standards, such as the International Finance Corporation's Sustainability Framework (IFC,2012), UN Millennium Development Goals (United Nations, 2008), UN Sustainable Development Goals (United Nations, 2015), and Global Compact (UN Global Compact, 2004).

Win the sponsor's full commitment: The case of Ecuador demonstrated the importance of training a sponsor in the initial program stages. Without sufficient early engagement, the sponsor cannot support implementation as thoroughly as required, resulting in logistical challenges and differences in opinion. It is therefore critical to gain early and ongoing engagement to ensure transparency and ease of program implementation (IFC, 2011). Without long-term commitment from the sponsor, the vital ongoing evaluation and coaching in the fourth pillar of the program cannot be guaranteed.

3.4 Finding balance between local and international supply

The challenge of balancing local and international supply chains arises from disparities in business management, processes, and procedures between large organizations and local small businesses (Warner, 2017). While international entities adhere to structured sourcing and procurement processes and stringent compliance demands, local businesses in developing countries typically operate within informal economies with fewer requirements and standards. This dichotomy presents hurdles for local businesses, as they often struggle to meet the pre-qualification criteria of large procuring entities, resulting in frustration due to exclusion from bidding processes and potential conflicts with local communities stemming from unfulfilled promises of employment and contracting opportunities. Adjustments in local procurement occur on both ends, with companies adapting financially and administratively to local procurement requirements, and local governments facilitating the formalization of local businesses and preparing them to meet minimum standards to qualify for contracts (IFC, 2011).

In response to this challenge, the Local Community Procurement Program (LCPP) approach aims to facilitate the entry of local suppliers and contractors into supply chains. By collaborating with larger companies to adapt their procurement and administrative processes and enabling small businesses to become qualified suppliers, the LCPP seeks to integrate them into larger companies' supply networks. These networks serve larger projects, with local suppliers and small businesses participating as direct or indirect suppliers across different tiers of the supply chain. The inclusion of local suppliers and small businesses will be based on their ability to contribute their knowledge and expertise, adding value to the overall project (Warner, 2017).

This initiative aims to strike a balance between community development and business growth (ICMM, 2022). At the international level, the standards aim to ensure social and economic development benefits for local small businesses through their inclusion and participation in larger projects that impact their regions. The commitment is to prepare both entities for their roles and facilitate their adaptation to different environments (United Nations – UNEP, 2015)

4. Conclusion

The Local Community Procurement Program™ (LCPP) emerges as a powerful tool for promoting inclusive supply chains and sustainable development in mining communities (World Bank Group, 2015). By maximizing efficiencies in the sponsor's supply chain and procurement process, the LCPP secures local content while developing the existing capacity of local communities and businesses to meet industry standards and demands. In doing so, it acts as a tool for conflict mitigation between the private sector and communities, promoting economic inclusion and stimulating community development. Case studies in Ecuador and Mexico illustrate the program's success in enhancing stakeholder engagement and trust, while its holistic approach ensures the inclusion of vulnerable groups and secures commitment from sponsors. The LCPP exemplifies a transformative model for driving positive change and fostering long-term prosperity in mineral-rich regions.

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6. References

Burchell, J. (2020). The Corporate Social Responsibility Reader. Routledge.

FITT (2008). Global Supply Chain Management. 5th Edition. FITT Skills. Forum for International Trade Training (FITT), Canada.

Henisz, W.J. (2017). Corporate Diplomacy: Building Reputations and Relationships with External Stakeholders. Routledge.

ICMM (2012). Community Development Toolkit. International Council on Mining and Metals (ICMM), London, UK.

ICMM (2022). Mining Principles: Performance Expectations. International Council on Mining and Metals (ICMM), London, UK.

IFC (2007). A Good Practice Handbook for Companies Doing Business in Emerging Markets. No. 39916. International Finance Corporation, The World Bank.

IFC (2011). International Finance Corporation. A Guide to Getting Started in Local Procurement: For Companies Seeking the Benefits of Linkages with Local SMEs. No. 91717. International Finance Corporation, The World Bank.

IFC (2012). International Finance Corporation. Sustainability Framework. International Finance Corporation, The World Bank.

MAC (2024). Towards Sustainable Mining (TSM) Protocols. Mining Association of Canada.

Roseland, M. (1992). Toward Sustainable Communities. National Round Table on the Environment and the Economy, Ottawa, Canada.

UN (2008). UN Millennium Development Goals Report 2015, United Nations.

UN (2009). General Assembly. Declaration on the Rights of Indigenous Peoples. United Nations.

UN (2015). The Agenda 2030 for Sustainable Development. United Nations.

UNEP (2015). Transforming our World: The 2030 Agenda for Sustainable Development. Knowledge Repository. United Nations Environment Program.

UN Global Compact (2004). The Ten Principles of the UN Global Compact, United Nations Global Compact.

Warner, M. (2017). Local Content in Procurement: Creating Local Jobs and Competitive Domestic Industries in Supply Chains. Routledge.

World Bank Group (2015). Procurement Innovation Challenge.

Stakeholder Approval: Navigating Project Readiness through Dialogue-Based Engagement

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1. Introduction

Traditionally, stakeholder engagement has been based on “stakeholder mapping”, the assessment of the power and influence of stakeholders, a process popularized by Mitchell, Agle, and Wood (1997) in their Stakeholder Salience Model. This well-established approach has found relevance across industries for two decades, as it provides a systematic means to categorize stakeholders based on their potential impact on an organization.

In recent years, however, there has been a notable shift in the realm of stakeholder engagement. Extensive field research and hands-on experience have emphasized the importance of broadening this examination beyond mere power dynamics and influence, to encompass the attitudes and sentiments guiding stakeholders' involvement with a project or organization. This concept is backed by academic research on the importance of stakeholder sentiment, and its impact on decision-making and relationships. Freeman (1984) examined the conceptual foundations of the stakeholder notion and advocated for organizations to shape their engagement strategies based on their interactions with crucial stakeholders. He further introduced the method of sentiment mapping, which adds a crucial dimension to stakeholder engagement by emphasizing the assessment of stakeholders' emotions, perceptions, and attitudes. This method acknowledges that stakeholders' relationships with a business are not solely transactional but are also influenced by subjective factors. By exploring stakeholders' sentiments, businesses gain insights into the emotional resonance of their decisions, actions, and projects. This sentiment mapping model is particularly applicable in modern business contexts, where understanding and aligning with stakeholders' values and expectations play a role in building relationships, enhancing reputation, and fostering a supportive community around the business's endeavours.

Inspired by Freeman's research, an exploration was undertaken into the efficiencies of analyzing stakeholder views and attitudes towards the project, introducing a distinctive approach — one centered around approval-based perspectives. Recognizing that each stakeholder embodies different levels of trust, curiosity, perceptions, and attitudes that intricately influence their propensity to consent, a dialogue-based methodology was designed to draw out and capture these nuanced sentiments. This methodology facilitates a customized approach that resonates with stakeholders and serves as an essential feedback mechanism for the project. Employing this approval-based approach, the project can benefit from an inclusive strategy that ensures stakeholder needs, concerns, and expectations are not only addressed but also integrated throughout the project's development, increasing its resonance and acceptance within the community.

In a rapidly evolving world where a deep understanding of social dynamics and community expectations are critical to project success, an approval-based approach provides a strategic shift that enhances stakeholder engagement, promotes transparency, and ultimately contributes to the achievement of sustainable project outcomes.

2. Materials and methods

The approval-based approach aims to adeptly capture stakeholder sentiment, guiding community relations practitioners through a streamlined and logical process. The strategic objective is for stakeholders to reach approval or acceptance, enabling the project to advance based on the dialogue. This approach considers stakeholder approval as the desired outcome, recognizing that the universe of stakeholders will likely span all four categories. Stakeholder data and their sentiment collected in the field are categorizes from opposition to approval, and subsequently, the analysis translate to effective engagement strategies (Figure 1). This process provides the opportunity to bring along stakeholders who remain skeptical, nurturing enduring trust-based relationships.

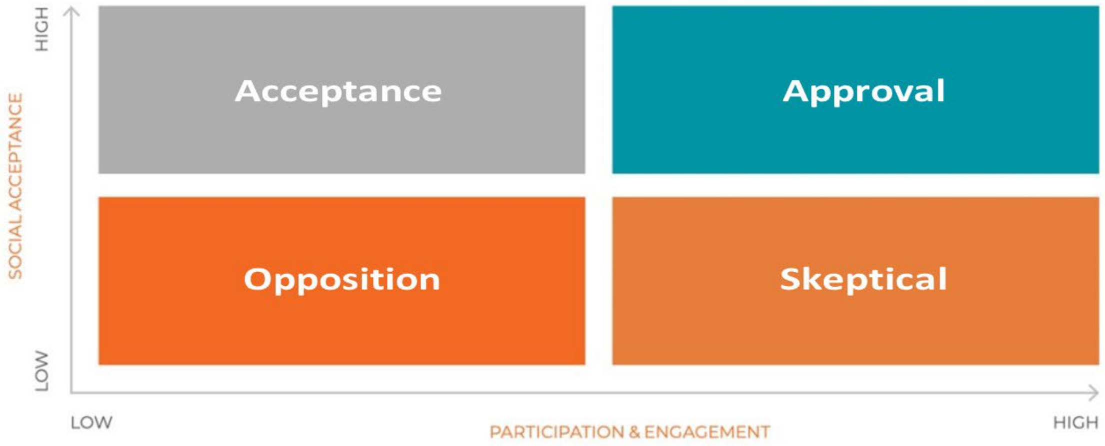

Figure 1. The four categorizations of stakeholder sentiments used to classify each stakeholder based on data collected for Stakeholder Approval

To harness stakeholder sentiment for effective engagement and approval, this process can be broken down into five steps:

i. Data gathering and analysis: Commencing with data collection, stakeholder sentiments was classified from opposition to approval, facilitating a clear understanding of their positions.
ii. Tailored strategies: Segmented by type of sentiment (e.g., disbelieves, uncertainty, distrust, etc.), custom strategies, messages, and engagement approaches respecting stakeholder position and sentiments was created, and ensuring effective communication alignment.
iii. Ongoing monitoring: Insights from stakeholder interactions fuel continuous progress evaluation, gauging the efficiency of the methodologies and strategies.
iv. Adaptive approach: The Stakeholder Approval methodology is inherently flexible, promptly responding to stakeholder feedback, enabling nimble and responsive engagement.
v. Building trust and collaboration: Fostering dialogue and pre-empting reactions to significant events, the approach cultivates trust, evolving sentiment from opposition to approval, and fostering enduring partnerships.

3. Results and Discussion

3.1 The Stakeholder Approval Model

Based on the approved-based approach described in section 2, the journey towards stakeholder approval encompasses navigating through four distinct phases that provide insights into stakeholder sentiment and perspectives. The Stakeholder Approval Model is rooted in field experience in stakeholder engagement, recognizing the profound process that stakeholders undergo. Their ideas, feelings, and perceptions continually shape their stance, whether it is positive or negative, towards a project or company.

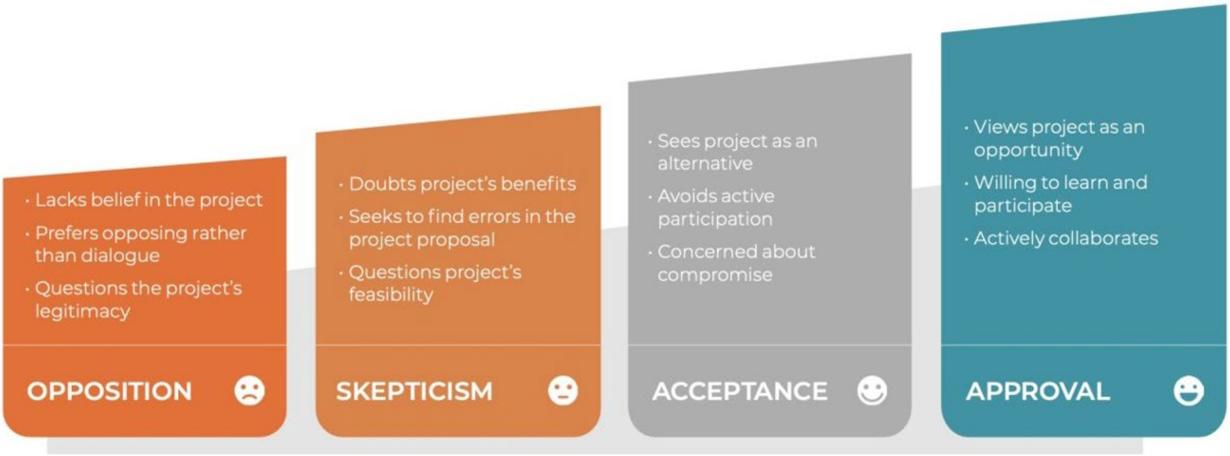

Figure 2. The four phases of stakeholder approval within the Stakeholder Approval framework range from “opposition”, indicating the least approval to “approval” signifying th highest level of approval from project-affected stakeholders

The four stakeholder approval phases serve as crucial waypoints in this journey (Figure 2):

- Opposition: In this phase, stakeholders hold mistrust towards the project's viability or the company. This sentiment is often extended to encompass both the project proponents and governmental bodies. Dialogue is limited, with a preference for expressing opposition over fostering open communication.
- Skepticism: Stakeholders harbour doubts about the project's potential benefits. They seek to thoroughly assess available evidence, scrutinize arguments, and verify the project's legitimacy.
- Acceptance: Stakeholders recognize the project's regional potential. Some express interest, but limited involvement, while others, though accepting, prefer avoiding public exposure and remain passive.
- Approval: This phase marks stakeholders' recognition of the project as an opportunity, particularly in the context of mining. They actively engage, showing a readiness to collaborate, learn, and contribute to the project's success.

The Stakeholder Approval approach respects and values the diverse perspectives of stakeholders, utilizing these stages to assess sentiment, foster meaningful dialogue, respond to inquiries, and clarify misconceptions. This inclusive and comprehensive understanding of stakeholder viewpoints enables the development of effective engagement strategies aimed at navigating the path to approval. Cultivating strong relationships and committing resources, time, and effort facilitate progress based on trust, cooperation, and mutual understanding.

3.2. Potential Outcomes for Industry and Project-Affected Communities

The Stakeholder Approval methodology can serve as a strategic and holistic approach to navigating these complex landscapes. By understanding and addressing stakeholder sentiment, this methodology has potential to unlocks a multitude of benefits for companies and project-affected communities.

The benefits for businesses encompass: 1) Improved stakeholder relationships: By understanding and addressing stakeholder sentiment, companies can build dialogue leading to maintaining positive relationships, resulting in smoother project delivery and reduced conflict. 2) Efficient resource allocation: With approval-driven insights, organizations can allocate resources more effectively, focusing efforts on areas that matter most to stakeholders and optimizing budget and time management. 3) Effective risk management: Anticipating and addressing concerns at different sentiment stages minimizes the risk of conflict, ensuring a proactive approach to risk management and reputation protection. 4) Informed decision-making: In-depth stakeholder sentiment analysis provides valuable input for decision-making, enabling organizations to align project strategies with stakeholder views and expectations. 5) Improved reputation and social acceptance through collaboration: Demonstrating a commitment to transparent, dialogue-based engagement builds positive reputation and social acceptance, fostering collaboration with investors, partners, and community stakeholders for long-term success. 6) Enhanced trust and collaboration: Clearly communicating any changes made in response to stakeholder input, and explaining the reasons behind decisions, even when recommendations cannot be accommodated, helps build trust and leads to increased collaboration and shared responsibility, as illustrated in the IAP2 (2007) Spectrum of Public Participation. 7) Alignment with International standards: Demonstrate commitments with internationally recognized standards and best practices, such as the IFC World Bank Stakeholder Engagement: A Good Practice Handbook for Companies Doing Business in Emerging Markets, ICMM's Principle #10 Stakeholder Engagement, and the MAC TSM Indigenous and Community Relationships Protocol.

Aside from business benefits, the Stakeholder Approval model is aimed to address community concerns while benefitting them: 1) Safety and well-being: Ensuring the safety and well-being of the community is often the top priority, as it directly impacts the quality of life and overall satisfaction of community members. 2) Transparency and inclusion: Promoting transparency and inclusion helps build trust and fosters a sense of ownership among community members, ensuring their voices are heard and considered in decision-making processes. 3) Economic opportunities: Providing financial benefits, job opportunities, and supporting local development projects can significantly improve the community's economic stability and overall prosperity. 4) Mutual respect and care: Demonstrating genuine care for the community and respecting their values and concerns fosters a positive relationship, promoting mutual understanding and collaboration. 5) Participation and empowerment: Encouraging community members to actively participate in discussions and decision-making processes empowers them to have a meaningful impact on shaping their own neighborhood.

4. Conclusions

The evolution of stakeholder engagement, from Freeman's concepts to the practical approach embodied in the Stakeholder Approval methodology, has seen a significant shift. This approach goes beyond power and influence, delving into sentiments and perceptions to guide businesses in a more effective, transparent, and strategic manner. This innovative approach not only facilitates the management of resources and the measurement of relationship progress, but also delivers tangible results such as project approvals, collaborative partnerships, inclusive supply chains, and socioeconomic benefits. The journey from theory to practice has revealed a path that not only enhances project viability, but also fosters lasting stakeholder alliances, marking a pivotal shift in contemporary business strategies.

5. Acknowledgments

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6. References

Freeman, R.E. (1984). Strategic Management: A Stakeholder Approach. Cambridge University Press, Cambridge.

Henisz, W.J. (2014). Corporate Diplomacy: Building Reputations and Relationships with External Stakeholders. Greenleaf Publishing Limited, Sheffield.

IFC (2010). Strategic Community Investment. International Finance Corporation, Washington, DC.

Mitchell, R.K., Agle, B.R. and Wood, D.J. (1997). Toward a Theory of Stakeholder Identification and Salience: Defining the Principle of Who and What Really Counts. The Academy of Management Review. 22(4): 853-886.

Roseland, M. (2005). Toward Sustainable Communities. New Society Publishers, Gabriola Island.

Warner, M. (2011). Local Content in Procurement: Creating Local Jobs and Competitive Domestic Industries in Supply Chains. Greenleaf Publishing Limited, Sheffield.

Zanddvliet, L. and Anderson, M.B. (2009). Getting it Right: Making Corporate–Community Relations Work. Greenleaf Publishing Limited, Sheffield.

Social License Narrative in the Mining Sector from a Cultural Perspective in Europe

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1. Intorduction

The concept of social license to operate (SLO), rooted in corporate social responsibility (CSR), emphasizes the importance of companies engaging with stakeholders and addressing social and environmental concerns (Verrier et al., 2022). To gain and maintain a social license, organizations must effectively communicate, address concerns, and demonstrate commitment to sustainability (Prno & Slocombe, 2012). Losing a social license can result in opposition, protests, and reputational damage, while maintaining one can increase trust and competitiveness (Boutilier et al., 2012).

Moreover, cultural perspectives wield significant influence in the mining sector, shaping the way local communities perceive and interact with operations. For instance, in certain indigenous communities in Canada and Europe, mining is viewed as a threat to their way of life and the environment, sparking conflicts and resistance against mining companies (Gobby et al., 2022). Conversely, in some Australian regions, mining is regarded as a catalyst for economic growth and job opportunities, garnering support for mining projects (Eklund, 2015). Grasping and respecting such cultural perspectives is not only crucial but also enlightening for sustainable mining practices (Moomen et al., 2020).

By conducting an extensive literature review and in-depth analysis of case studies, this study seeks to uncover how companies in the European mining sector can obtain and sustain their social license narrative to address cultural variations, with a specific focus on comparisons with Canada and Australia. These countries were chosen due to their prominent mining industries and diverse cultural perspectives, shedding light on potential strategies for navigating cultural differences in the European context.

By conducting a thorough narrative analysis, the study aims to shed light on the impact of cultural components on the social licence for mining activities and how companies can leverage cultural diversity to strengthen their ties with local communities.

Specifically, this study will examine the cultural factors that influence how communities perceive and respond to mining projects, the role of historical and societal values in shaping attitudes towards mining, and the importance of engaging with cultural norms and traditions in securing SLO. Finally, we discuss mining companies' challenges and opportunities in navigating European cultural dynamics and suggest strategies for building stronger relationships with local communities.

2. Literature Review

2.1 Cultural Factors Influencing Social License in Europe

From a cultural perspective in Europe, the issue of social license in the mining sector is closely tied to the historical and cultural significance of lands and resources to local communities. Many European countries have deep-rooted cultural ties to lands and the environment, with communities often having a strong sense of ownership and connection to the resources (Tost et al., 2021).

Furthermore, the history of mining in Europe has left a legacy of environmental degradation, health issues, and social unrest in many communities (Mononen et al., 2022). One example of the environmental degradation caused by mining is the case of a mining company in Spain. The company has a long history of mining activities in the region, including a large open-pit copper mine near Minas. Some mining activities have contaminated rivers and groundwater with heavy metals such as arsenic and lead, causing significant harm to the local ecosystem and community health (Olìas & Nieto, 2015). Around Tharsis in Spain, according to Chopin et al., (2003) residents have reported increased rates of respiratory problems and cancer-related illnesses due to exposure to mining-related pollutants. These health issues have created a sense of mistrust towards mining companies, as residents have felt that their well-being has been sacrificed for profit. Social unrest has also been a common consequence of mining activities in Romania. In Rosia Montana, plans for a large-scale gold mining project led to widespread protests and demonstrations by residents concerned about the project's environmental and cultural impacts. The resulting conflict between the mining company and the community has created a tense and polarized atmosphere, further eroding trust between the two parties. This legacy has contributed to a sense of scepticism and distrust towards mining companies, making it more difficult for companies to earn and maintain a social licence to operate (Syn, 2014).

Given the importance of maintaining social license in the mining sector and the potential impact on local communities, the European Critical Raw Materials Act 2023 also includes provisions to strengthen industrial competitiveness and enhance sustainability by identifying essential materials, diversifying supply chains, promoting recycling, and encouraging innovation (European Commission, 2023). Despite these materials' strategic importance, ongoing debates exist about balancing extraction with environmental and social concerns (Filho et al., 2023).

In recent years, there has been a shift in the cultural significance of mining in European societies. Traditional mining communities, once reliant on the industry for their livelihoods, have declined, resulting in a loss of cultural identity associated with mining (Shackleton, 2020). However, mining critical raw materials has emerged as a pressing issue in Europe and globally. The European Union has identified 34 essential raw materials crucial for its economy but are vulnerable to supply disruptions. These materials are utilized in key industries such as renewable energy, electronics, and automotive manufacturing. To address this challenge, the European Union actively reduces its reliance on imported critical raw materials by promoting domestic production and recycling. The EU also focuses on enhancing resource efficiency and advocating for sustainable practices in raw material usage. This signifies a shift in focus towards ensuring a stable and sustainable supply of essential resources for the future.

While Europe has limited domestic sources of some critical raw materials, there is ongoing debate about the balance between the need for these materials and the potential environmental and social impacts of extracting them. Some argue that Europe should prioritize recycling, resource efficiency, and responsible sourcing practices to reduce reliance on mining. In contrast, others advocate for responsible mining practices and investment in sustainable extraction technology. Ultimately, balancing Europe's demand for critical raw materials and addressing the concerns of local communities and environmental advocates is a complex and ongoing challenge (European Commission, 2023).

In the mining sector in Australia, the concept of social licence is of utmost importance due to the significant impact that mining activities can have on the environment and local communities. This is further highlighted by the Australian Government's recognition of 31 resource commodities as critical minerals as of February 2024 (Australian Government, 2024). Moreover, cultural perspective also plays a crucial role in the mining sector in Australia, with many mining projects located on land that holds significant cultural importance to Indigenous peoples. It is imperative for mining companies to actively engage with Indigenous communities and respect their cultural heritage to maintain a positive relationship and secure social licence to operate. Failure to do so can lead to regulatory delays, protests, and reputational damage for the company (Kemp & Owen, 2017). By acknowledging and respecting the cultural significance of the Indigenous Peoples lands, mining companies can establish stronger connections with local communities and ensure sustainable operations in the long term.

Regarding Canada, the importance of obtaining a social licence in the mining sector is directly linked to the critical raw materials identified by the Canadian government. These critical minerals are essential for various industries, including technology, renewable energy, and national defence. Without the necessary social licence, mining projects that extract these critical minerals may face opposition and delays, ultimately impacting Canada's ability to secure a stable supply of these vital resources. By recognizing and addressing the concerns of Indigenous communities and other stakeholders, mining companies can obtain social licences for their projects and ensure a sustainable supply chain for critical raw materials. Meaningful consultation and collaboration with Indigenous communities can lead to mutually beneficial agreements that respect cultural values and protect the environment while supporting Canada's strategic interests in critical minerals (Poelzer et al., 2023). Companies in the mining sector must prioritize these relationships and engage in transparent and respectful partnerships to secure the social licence needed to extract critical raw materials for the benefit of all stakeholders involved.

In Europe despite the increasing interest for critical raw materials, the mining sector is facing increasing scrutiny from both regulators and civil society organizations. The continent has a long history of mining activities, with some mines dating back centuries. In the 18th and 19th centuries, the mining sector in Europe often operated with little regard for social licence or cultural perspectives. Mines were typically owned and operated by wealthy elites, leading to exploitative labour practices and environmental degradation in surrounding communities. However, in recent years, there has been a growing awareness of cultural perspectives connected to mining activities, leading to increased pressure on companies to engage more actively with local communities and stakeholders (Lesser et al., 2021).

Another example that illustrates the impact of cultural components on SLO for mining activities in Europe is the controversy surrounding the proposed lithium mining project in Finland. The project, which aims to extract lithium for use in electric car batteries, has faced opposition from the local Saami population, an indigenous community with a deep connection to the land. The Saami people have expressed concerns about the project's potential environmental impact on their traditional lands, as well as the loss of cultural heritage and disruption to their way of life. This cultural resistance has led to protests, legal challenges, and a lack of social acceptance for the mining project among the Saami and other local communities (Jartti et al.,2020).

In contrast, according to Stihl (2022), the Swedish town of Kiruna provides an example of how cultural components can support the social licence for mining activities. The town has a long history of mining for iron ore, which has been a key driver of economic development and employment in the region. The local community is enormously proud of the mining industry, which is seen as a source of identity and prosperity. This cultural acceptance of mining has facilitated ongoing support for the industry despite potential environmental concerns and impacts on the landscape. Moreover, Barakos and Mischo (2020) stress the importance of incorporating sustainable and social license to operate (SLO) attributes alongside technical considerations in the early design stages of mining operations. Their study applies this approach to rare earth element projects in Sweden and Alaska, showing that considering SLO factors during the mining method selection process can significantly impact both the chosen method and economic outcomes.

Overall, the re-evaluation of SLO in Europe is driven by recognizing the strategic importance of critical raw materials for the continent's economy and competitiveness. By addressing the challenges related to raw material supply, Europe aims to ensure a sustainable and resilient industrial base for the future.

3. Analysis

Mining activities in Europe, according to Di Noi & Ciroth (2018), have been known to have widespread negative impacts on the environment, leading to concerns about irreversible damage to the land, water sources, and air quality in affected communities. This environmental degradation can result in the loss of biodiversity, disruption of ecosystems, and contamination of water sources, posing risks to local wildlife and the health of residents who rely on these resources for sustenance. Furthermore, the displacement of residents from their homes and livelihoods due to mining activities can have devastating social and economic consequences for communities. The forced relocation of people can lead to the fragmentation of communities, loss of cultural heritage, and exacerbate existing inequalities among residents. In addition, concerns about the long-term health impacts of mining activities on residents cannot be overlooked. The release of toxic substances into the air and water, as well as the generation of hazardous waste, can lead to a range of health issues, including respiratory problems, neurological disorders, and increased cancer risks for those living near mining sites. Moreover, social conflicts can arise from disputes over land rights, access to resources, and the distribution of benefits from mining activities. In many cases, mining companies may prioritize profits over the well-being of local communities, leading to tensions and resistance from residents who feel marginalized or exploited by these operations.

According to Komnitsas (2020), companies should use the concept of Social Licence to Operate (SLO) based on cultural characteristics that led to the diminishing of mining in Europe because it is essential for building trust and acceptance among local communities. As it has been observed, in Europe, the mining industry's decline was partly due to conflicts with local populations, environmental concerns, and disregard for cultural heritage. By incorporating cultural characteristics into their SLO approach, companies can better understand the needs and values of the communities in which they operate. This can help prevent conflicts and ensure the company's activities align with local customs and traditions (Rodolaki & Barakos, 2023).

Additionally, by respecting cultural heritage and meaningfully engaging with local communities, companies can foster positive relationships and create a more sustainable and mutually beneficial partnership. This can help mitigate risks, enhance reputation, and ultimately secure the social licence needed to operate successfully in the long term (Sinclair & Coe, 2024).

3.1 Engaging with Cultural Norms and Traditions

To secure social license in mining in Europe, companies must respect cultural norms, prioritize local communities, and incorporate their perspectives, including using free, prior, and informed consent (FPIC). Engaging with local organizations and leaders, identifying common goals, and collaborating on solutions can build trust and create shared value (Poelzer et al., 2022).

3.2 Challenges and Opportunities in Navigating Cultural Dynamics

Navigating cultural dynamics presents challenges for European mining companies, including language barriers, differing cultural norms, and historical tensions. These challenges can hinder securing social licenses and maintaining positive relationships with local stakeholders. However, companies can overcome these obstacles by investing in cultural competency training, prioritizing community engagement, and aligning practices with local values to build stakeholder trust and demonstrate commitment to responsible mining (Rodolaki et al., 2023).

3.3 Strategies for Building Stronger Relationships with Local Communities

To secure a social license in Europe, companies should conduct cultural heritage assessments, engage with local communities to protect significant sites and work to minimize impacts on cultural heritage. Meaningful dialogue with stakeholders, transparent decision-making, and partnerships with cultural institutions and indigenous groups are vital strategies for building trust and demonstrating social responsibility (Kolovos, 2013).

4. Conclusions and Future Recommendations

Future recommendations include investing in community engagement initiatives, cultural competency training for staff, and sustainability practices that align with local values to enhance the understanding and implementation of cultural perspectives in the mining sector. By integrating Indigenous knowledge, environmental conservation practices, and community engagement strategies into mining operations, companies can navigate cultural dynamics, build strong partnerships, and secure social license in Europe.

Moreover, it is recommended that narrative analysis with AI technology be utilized to further enrich research on social license narratives in the mining sector. This would offer valuable insights for policymakers, industry stakeholders, and the public. By harnessing the power of AI to analyze and interpret cultural factors shaping social license narratives, mining companies can make informed decisions, improve stakeholder relationships, and drive sustainable practices in the industry.

In conclusion, integrating cultural perspectives and AI-driven analysis is critical to fostering a more sustainable and socially responsible European mining sector. By prioritizing cultural understanding, community engagement, and technological innovation, companies can secure their social license to operate and contribute to the well-being and prosperity of local communities and the environment.

5. References

Australian Government, (2024). Geoscience Australia. Retrieved from: https://www.ga.gov.au/scientific-topics/minerals/critical-minerals

Barakos, G. and Mischo, H., (2020). Insertion of the social license to operate into the early evaluation of technical and economic aspects of mining projects: experiences from the Norra Karr and Bokan Dotson rare earth element projects. The Extractive Industries and Society. 8(2): 100814.

Boutilier, R.G., Black, L. and Thomson, I. (2012). From metaphor to management tool: How the social license to operate can stabilise the socio-political environment for business. In the Proceedings of the International Mine Management Conference, AusIMM, Melbourne. pp 227-237.

Chopin, E.I.B., Black, S., Hodson, M.E., Coleman, M.L. and Alloway, B.J. (2003). A preliminary investigation into mining and smelting impacts on trace element concentrations in the soils and vegetation around Tharsis, SW Spain. Mineralogical Magazine. 67(2): 279-288.

Di Noi, C. and Ciroth, A. (2018). Environmental and Social Pressures in Mining. Results from a Sustainability Hotspots Screening. Journal of Resources. 7(4): 80.

Eklund, E. (2015). Mining in Australia: An historical survey of industry-community relationships. Journal of the Extractive Industries and Society. 2(1): 177-188.

European Commission (2023). Addressing the balance between the need for critical raw materials and environmental and social impacts. Retrieved from https://single-market-economy.ec.europa.eu/publications/study-critical-raw-materials-eu-2023-final-report_en

Filho, W.L., Kotter, R., Özuyar, P.G., Abubakar, I.R., Eustachio, J.H.P.P. and Matandirotya, N.R. (2023). Understanding Rare Earth Elements as Critical Raw Materials. Journal of Sustainability, 15(3): 1919.

Gobby, J., Temper, L., Burke, M. and Ellenrieder, N. (2022). Resistance as governance: Transformative strategies forged on the frontlines of extractivism in Canada. The Extractive Industries and Society. 9: 100919.

Jartti, T., Litmanen, T., Lacey, J. and Moffat, K. (2020). National level paths to the mining industry's Social License to Operate (SLO) in Northern Europe: The case of Finland. J The Extractive Industries and Society. 7(1): 97-109.

Kemp, D. and Owen, J.R. (2017). Countervailing Power and the Global Mining Industry. Routledge.

Kolovos, C.J. (2013). Mining in consistency with long term planning: A key element to social acceptance. In Proceedings of the 6th International Conference on Sustainable Development in the Minerals Industry (SDIMI), Milos Island, Greece, 30 June–3 July 2013.

Komnitsas, K. (2020). Social License to Operate in Mining. Present Views and Future Trends. Journal of Resources, 9(6): 79.

Lesser, P., Gugerell, G., Poelzer, G., Hitch, M. and Tost, M. (2021). European mining and the social license to operate. The Extractive Industries and Society, 8(2): 100787.

Mononen, T., Kivinen, S., Kotilainen, J.M. and Leino, J. (2022). Social and environmental impacts of mining activities in the EU. European Parliament. Retrieved from: http://www.europarl.europa.eu/supporting-analyses

Moomen, A., Lacroix, P., Bertolotto, M. and Jensen, D. (2020). The Drive towards Consensual Perspectives for Enhancing Sustainable Mining. Journal of Mineral Resources and Sustainable Development. 9(12): 147.

Olìas, M. and Nieto, J.M. (2015). Background Conditions and Mining Pollution throughout History in the Rio Tinto (SW Spain). Journal of Environments. 2(3): 295-316.

Poelzer, G., Frimpong, R., Poelzer, G. and Noble, B. (2023). Community as Governor: Exploring the Role of Community between Industry and Government in SLO. Journal of Environmental Management. 72(1): 70-83.

Poelzer, G., Gugerell, K., Tost, M., Kyllönen, KM. and Lesser, P. (2022). The Societal Dimension of SLO in European Mining. The Societal Dimension of SLO in European Mining. In: Wood, G., Górski, J., Mete, G. (eds) The Palgrave Handbook of Social License to Operate and Energy Transitions. Palgrave Studies in Energy Transitions. Palgrave Macmillan, Cham. pp 1-19.

Prno, J. and Slocombe, D.S. (2012). Exploring the origins of 'social license to operate' in the mining sector: Perspectives from governance and sustainability theories. Resources Policy. 37(3): 346-357.

Rodolaki, C. and Barakos, G. (2023). Understanding the Social License to Operate from a Cultural Perspective: The Case Studies of Australia, Greece, and India. Journal of Materials Proceedings. 15(1): 3.

Rodolaki, C., Barakos, G. and Hitch, M. (2023). The role of intercultural differences and challenges faced in negotiating active mine site's rehabilitation objectives from Africa to Europe. The Extractive Industries and Society. 16(2): 101362.

Shackleton, R.T. (2020). Loss of land and livelihoods from mining operations: A case in the Limpopo Province, South Africa. Journal of Land Use Policy, 99: 104825.

Sinclair, L. and Coe, N.M. (2024). Critical Mineral Strategies in Australia: Industrial upgrading without environmental or social upgrading. Journal of Resources Policy. 91: 104860.

Stihl, L. (2022). Challenging the set mining path: Agency and diversification in the case of Kiruna. The Extractive Industries and Society. 11(4): 101064.

Syn, J. (2014). The Social License: Empowering communities and a Better Way Forward. A Journal of Knowledge, Culture and Policy. 28(3-4): 318-339.

Tost, M., Ammerer, G., Kot-Niewiadomska, A. and Gugerell, K. (2021). Mining and Europe's World Heritage Cultural Landscapes. Journal of Resources. 10(2): 18.

Verrier, B., Smith, C., Yahyaei, M., Ziemski, M., Forbes, G., Witt, K. and Azadi, M. (2022). Beyond the social license to operate: Whole system approaches for a socially responsible mining industry. Journal of Energy Research and Social Science. 83: 102343.

Environmental, Social & Governance Reporting

Managing ESG Risks in Mining Finance – Strengthening the Outside-In View

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1. Introduction

KfW IPEX-Bank is a wholly-owned subsidiary of the German state-owned bank KfW. As an independent financial institution operating under competitive conditions in the market and being a specialist for international project and export finance with tailored medium- and long-term financing solutions and proven industry expertise, KfW IPEX-Bank's mission is to provide financings to support the German and European economy as part of the legal mandate of KfW.

In fulfilling this mission, KfW IPEX-Bank has successfully been active in mining finance for many years, mainly supporting European companies in exporting mining equipment or in securing raw materials supply. In doing so, KfW IPEX-Bank has been involved in mining activities in many parts of the world and for various minerals, thus also gaining extensive experience in assessing ESG risks.

2. ESG-Related aspects in mining finance

The increasing focus on ESG-related aspects is a general trend in all parts of the economy and also the society, and obviously this is especially relevant for the mining industry with its impact on many ESG elements. Thus, the importance of the assessment of environmental and social aspects as well as issues of good governance has increased significantly in mining finance for quite a while already, covering the whole process from business development, due diligence and decision making to monitoring and reporting until the final repayment of the financing.

In this assessment of ESG-related aspects, the focus has mainly been on the inside-out perspective in the past: Banks have considered the impacts of the financed transactions regarding ESG aspects and the overall transformation towards a "greener" portfolio. In this context and amongst other things, KfW IPEX-Bank implemented a sustainability guideline some years ago to ensure that all financings are environmentally and socially sound. For many years, KfW IPEX-Bank has also been a signatory to the Equator Principles[1], a framework intended to serve as a common baseline for financial institutions to identify, assess and manage environmental and social aspects when financing projects.

The awareness has also increasingly been on the structured assessment of the outside-in perspective: Banks are analysing how ESG risks influence the "real" risks of the financings and the portfolio. As this approach focuses on the risks for the banks, there is also growing guidance by the banking supervision authorities on what is expected in this field. Thus, banks are implementing additional internal processes and striving to collect further data and information to fulfil these requirements.

Obviously, the two perspectives can be combined and/or interdependent. For instance, this is the case when a negative ESG effect of a financing (i.e. inside-out effect) results in a poor reputation of the financed company or project and thus of the financing bank behind it (i.e. outside-in effect).

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[1] https://equator-principles.com

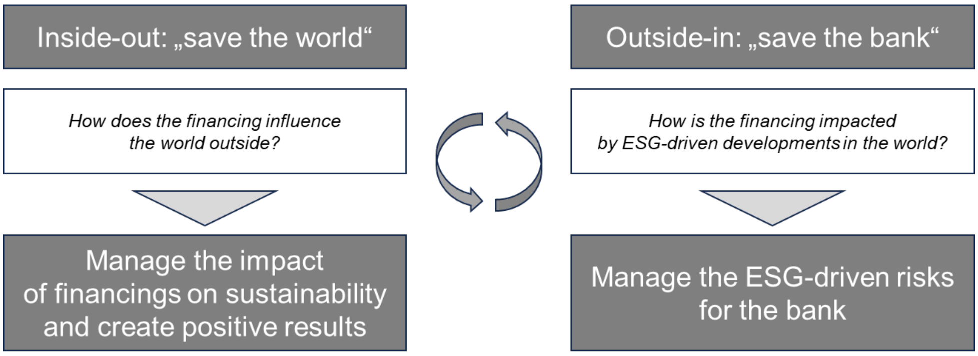

Figure 1. KfW IPEX-Bank's understanding of the different views of ESG-related aspects.

3. Strengthening the outside-in view

3.1 The Outside-in View of ESG Risks

For KfW IPEX-Bank, ESG risks are not an independent risk type but rather a risk driver for the business model and the risk profile and therefore included in several other risk types. The influence of ESG risks on other risk types can materialise both by physical effects and by transitory effects – and both in the short term (e.g., possible losses due to climate-related extreme weather events) and in the medium to longer term (e.g., possible "stranded assets" and losses due to changing regulation or market dynamics). This can impact the bank's portfolio via affected industry sectors, individual borrowers, assets or collateral values and countries. And this again may also give rise to potential consequential risks with an impact on the bank via other risk types.

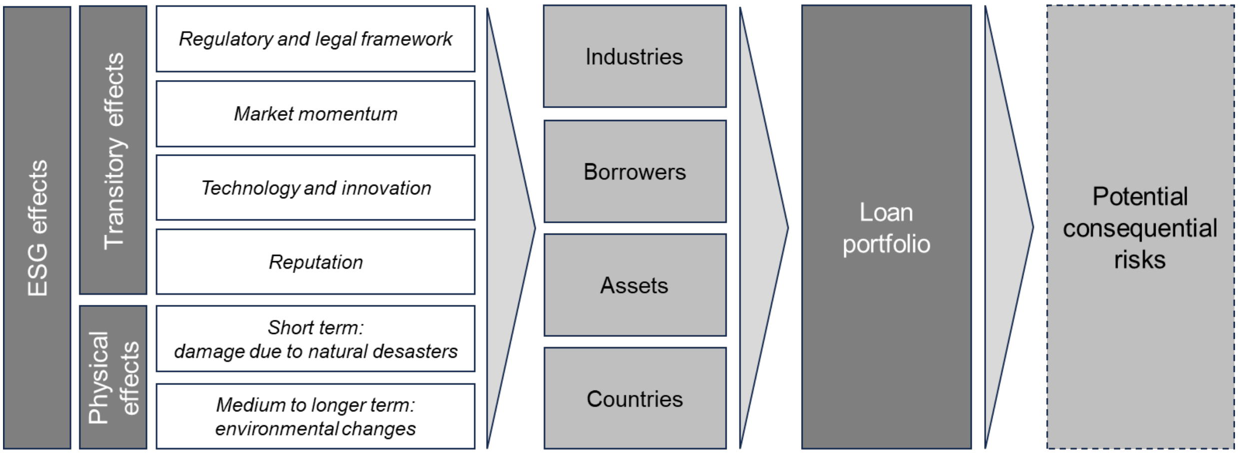

Figure 2. KfW IPEX-Bank's understanding of the outside-in perspective.

As a consequence, ESG risks must be taken into account and implemented in the risk management processes for the other risk types of the bank. This understanding of the outside-in perspective of ESG risks is also in accordance with the relevant regulatory requirements and guidance, e.g. the European Banking Authority's Guidelines on Loan Origination and Monitoring (EBA/GL/2020/06)[2] or the German Federal Financial Supervisory Authority's Minimum Requirements for Risk Management (MaRisk)[3]. In fact, the banking supervision authorities have been putting significant emphasis on the assessment and management of ESG risks over the last years.

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[2] https://www.eba.europa.eu/legacy/regulation-and-policy/regulatory-activities/credit-risk/guidelines-loan-origination-and#activity-versions

[3] https://www.bafin.de/SharedDocs/Downloads/EN/Rundschreiben/dl_rs_0523_marisk_ba_en.html

3.2 Examples for the Management of ESG Risks in KfW IPEX-Bank's Processes

Due to the broad possible effects of ESG-related aspects, the outside-in view of ESG risks is being implemented in various internal risk management processes – from individual financings to portfolio-oriented assessments. Thus, it is only possible to give a few examples to illustrate this development here.

- As part of the regular rating process, an ESG risk profile is defined for every financing, i.e. every company or project in the portfolio. The ESG risk profile assesses the potential negative financial effects on the company, or the project related to ESG events. For this, the ESG-driven risks are analysed in a structured manner and along with defined categories and scorings. The final ESG risk profile then is an important risk management instrument as it is used as an input for various other risk management processes. For example, the ESG risk profile is part of the approval process for new financings. In the end, this means that it will be more difficult to receive a positive decision for financing with a poor ESG risk profile compared to a similar financing opportunity with a stronger ESG risk profile.
- For existing financing in the portfolio, there is a well-proven process for the early detection of risks in order to identify potentially problematic financings at an early stage. This is intended to allow for the proactive management of the individual risks before the financings face more severe problems. In this process, ESG risks are also looked at as the development of ESG-related aspects can very well be early warning signals. Whenever the above-mentioned ESG risk profile for an existing company or project deteriorates over a defined threshold, this triggers a formal early warning signal and thus an explicit analysis of the reasons behind this as well as the possible or even necessary actions.
- While the examples above are related to risk management for individual financings, there are also processes that focus on portfolio-oriented risk management. For example, KfW IPEX-Bank has a system of limits regarding the exposure i.a. to borrowers, countries and industry sectors in order to manage the risks in the portfolio. For every industry sector, the above mentioned ESG risk profiles of all the financings within this industry sector are aggregated to derive an ESG risk score for the industry sector as a whole. This ESG risk score is then considered for the definition of the limit and thus of the allowed exposure for the relevant industry sector. Consequently, the allowed exposure for individual industry sectors is higher with a strong ESG score and vice versa (assuming all other relevant factors are identical). The idea behind this approach is that the bank should take less risk in industry sectors that are more vulnerable to ESG-driven risks. Obviously, this can influence the risk appetite and thus the possibility to provide financings for certain industry sectors, e.g. for the mining industry.
- On an even higher level of assessment, stress testing for the bank as a whole is an important element of the risk management toolbox. This approach is also used to assess and manage ESG risks. So far, the focus has been on climate change risks, but other ESG risks are also being looked at for stress testing. For example, the modelled impact of different scenarios of CO_2 emission right pricings on the bank's portfolio (via the impact on industry sectors and in the end the profitability of individual borrowers) is a possible view. In the end, the results of ESG stress tests can then again influence decisions on risk management processes on other levels and with impacts on the bank's approach to financing for certain industry sectors or borrowers.

4. Current Challenges

As the outside-in perspective is evolving, there are obviously some challenges that need to be addressed. Again, it is only possible to illustrate this with a few examples here.

- One very relevant aspect is the availability of data and information for the new processes. It is a challenge to gather and manage all the input that is required to implement the processes around the outside-in perspective of ESG risks; the examples given above for the processes of KfW IPEX-Bank for the management of ESG risks already illustrate this. As a consequence, mining companies might realise that banks ask for additional data and information throughout the financing process. For example, the implementation of client questionnaires specifically focussing on ESG-related aspects is a possible solution for this challenge.
- Another aspect is the very long term nature of at least some ESG risks, especially with respect to climate change. Firstly, the long term nature means that there are uncertainties regarding the future developments. And secondly, the long term nature is in contrast to many internal processes which have a shorter term approach. This makes it challenging to implement a well-calibrated system of risk management processes and derived decision making.

The further refinement of the processes around the outside-in view of ESG risks will definitely be a relevant issue for many banks in the near future.

5. Conclusions

It can be concluded that the assessment of environmental and social aspects as well as issues of good governance still is a pivotal element in mining finance. While the inside-out perspective remains important and is still evolving, banks are putting increased emphasis on the outside-in view as well.

In the end, the overall relevance of ESG risks in mining finance increases even more. For mining companies, this results in an even higher need to thoroughly address this including possibly the provisioning of more data and information in order to attract financing.

ESG Reporting in the Mining Sector: Case Studies from Greek Industry Leaders

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1. Introduction

As the global business landscape increasingly recognizes the significance of Environmental, Social, and Governance (ESG) factors, industries are under growing pressure to integrate sustainable practices into their operations (UNEP, 2020). The mining industry, known for its environmental and social implications, has become a focal point for ESG discussions. It tries to balance two conflicting needs: meeting the demand for raw materials necessary for the well-being of modern societies and eliminating the impact that mining works cause on nature, communities, and workers (Verrier et al., 2022; Maybee et al., 2023). In this context, the comprehensive nature of ESG reporting extends the concept of mining companies' non-financial performance beyond compliance with laws and regulations, prioritizing the proactive measures taken to address the complex challenges associated with responsible extractive practices. Furthermore, the significance of ESG reporting for the mining sector is connected with its link to global environmental issues and the mitigation of regional problems requiring a full understanding of impact assessment and permitting procedures, monitoring, and site-specific environmental protection and land rehabilitation interventions. ESG reporting is also pivotal in addressing mining operations' economic and social dimensions, particularly its contribution to fostering transparency, accountability, and stakeholder trust.

2. Materials and Methods

Focusing on prominent companies in the Greek industrial landscape, namely the Greek Public Power Corporation, Titan Cement Industry, Mytilineos Energy & Metals, and Hellas Gold mines, this study explores the ESG reports to showcase best practices, challenges encountered, and lessons learned. The data utilized were extracted from the publicly available reports of the four companies. Because of the variance in the adoption timelines of ESG strategies by each company, the reporting periods varied accordingly. The reports were subsequently juxtaposed against the Global Reporting Initiative (GRI, 2024) guidelines, a common set of metrics that can be used by all companies to report their impacts. Notably, the recently published GRI standard tailored to the mining sector was omitted since mining is only a part of the business activities for three of the four companies.

3. Results and Discussion

The *Public Power Corporation (PPC)* of Greece was founded in 1950 to generate, transmit, and distribute electrical power. To achieve this objective, it was necessary to exploit domestic lignite deposits. The two continuous surface mining complexes achieved in 2005 a record annual production of 70 Mt, having already transformed into the main pillars of regional development. Today, PPC's energy mix includes renewable energy sources, lignite, hydroelectric, natural gas, and petroleum units. Its business model is summarized in the phrase "creating shared value," implying the creation of shared benefits for the company, society, and environment. The three main axes of medium-term development include digital transformation, expansion into new products and customer-centric services, and the implementation of the 'Green Deal' in energy production, with the withdrawal of all lignite units by 2028, respecting the rights of workers, local communities, and the environment.

Initially, the company established a distinct Sector of Corporate Social Responsibility (CSR) within the Strategic Department, which was upgraded to the Sustainable Development Department in 2021. PPC has a list of 28 sustainable development issues (13 social, five economic, and ten environmental), and it has set priorities based on the probability and intensity of each impact. Regarding issues related to lignite mining operations, visual disturbance is considered highly probable to almost certain to occur, while dust emissions are considered a moderate to significant impact.

All ESG reports of PPC refer to mine restoration projects and interventions related to new land uses in restored areas. However, the progress in achieving the 'Green Deal' goals always holds a dominant position in the reports. According to the 2022 report, electricity production in 2020 accounted for 26.7% of Greece's CO_{2eq} emissions. PPC's lignite units reduced emissions by 81.85% from 2005 to 2021, reaching 8.41Mt CO_2 (PPC, 2024). *Titan Cement Group*'s lineage traces back to 1902, which was marked by the operation of the first cement plant in Elefsina, Greece. Since then, Titan has grown into an international cement and building materials producer with vertically integrated activity spanning across ten countries. In Greece, Titan infrastructure comprises three cement factories, a clinker grinding unit and a dry mortar production unit, four distribution stations, three port terminals, 26 quarries, and 31 readymixed concrete plans. Focusing on raw materials production, the Titan Group operates an additional 47 quarries in Southeast Europe, Turkey, Egypt, Brazil, and the USA.

Titan Cement Group adopts international trends in reducing its environmental footprint, with particular emphasis on CO_2 emissions reduction, both through enhancement in the production process and the development of low-carbon products. In this context, the 2023 annual ESG report highlights a 10% reduction of CO_2 emissions per tonne of cementitious products, a 37% decrease in net CO_2 intensity (measured in Kg/€), and a substantial increase in the percentage of green products to 23.4% (relative to figures from 2020). Additionally, the report underscores that 83% of Titan's quarries located in high biodiversity value areas have biodiversity management plans, 96% of quarries have rehabilitation plans, and 25% of areas affected by quarrying activities have already been rehabilitated.

Titan Cement Group has been issuing CSR reports since 2003. Nowadays, Titan's ESG reporting adheres to the Global Cement and Concrete Association (GCCA) sustainability framework, which encompasses five core pillars: (i) Health and Safety, (ii) Climate Change and Energy, (iii) Social Responsibility, (iv) Environment and Nature, and (v) Circular Economy. Moreover, Titan aligns its reporting with the United Nations Conference on Trade and Development (UNCTAD) Guidance, facilitating the correlation of key performance indicators with pertinent Sustainable Development Goals and specific targets for all focal domains.

In 2023, the ESG reports of Titan Group have achieved notable recognition from independent institutions, such as an AA rating for industry-specific ESG risks exposure by MSCI, a top 10% ranking in the construction materials industry according to the Standard & Poors Global Corporate Sustainability Assessment, and an overall ESG score of 64/100 by Moody's Analytics, 18 points above the European building materials sector's average score. Moreover, a 95% ESG Transparency Score from ATHEX ESG, and platinum-level recognition in the Forbes Transparency Index came as a recognition of the Group's dedication to transparency (Titan, 2024).

Mytilineos Energy & Metals is an international industrial and energy company operating through two business segments: Energy and Metallurgy. The Company strategically positions itself at the forefront of the energy transition while establishing itself as a reference point for competitive "green" metallurgy at both European and global levels. The company has expanded its operations to 40 countries, with a portfolio of 24 industrial production and renewable energy units.

In 2008, the company committed to the United Nations Global Compact (UNGC, 2024), addressing areas such as human rights, labor conditions, environment, and anti-corruption. The group's social accountability report was established in the same year following the GRI G3 level C guidelines. In 2010, a CSR committee was established at the Board of Directors level and similar structures across the group, along with a Climate Change Management Sector within the Legal and Regulatory Affairs Directorate. Additionally, the ESG report was certified at the GRI G3 level B. In 2012, the social accountability report was upgraded based on ISO26000 and OECD guidelines. The same year marked the cessation of bauxite residue deposition into the sea, and the group ranked first among Greek companies in a Bloomberg survey for its overall performance in ESG matters. Since 2016, Mytilineos Group has implemented the UN SDG Compass Tool to identify the alignment of sustainable development goals with its business activities. Since then, the group has consistently contributed to achieving 40 specific sub-goals classified into six main directions: (i) Addressing climate change, (ii) Supporting innovation and sustainable industrialization, (iii) Promoting safe and productive employment, (iv) Advancing inequality mitigation, (v) Committing to environmental protection, and (vi) Consistency in social responsibility. Finally, it is worth mentionable fact that Mytilineos Group has an independent Compliance Division, which is responsible for the design and implementation of the Anti-Bribery and ensures the compliance of the Management System that has been certified following the requirements of ISO 37001:2016 starting from 2024.

According to the latest ESG report, Mytilineos Group aims to achieve a 30% reduction in CO_2 emissions by 2030 compared to the reference year of 2019, with the goal of attaining carbon neutrality by 2050. In 2022, the reduction achieved was 15.5%. Additionally, the restoration rate of the total exploitable area impacted by mining reached 84.9%, just below the target of 87% (Mytlineos, 2024).

Hellas Gold is a mining company, a subsidiary of Eldorado Gold, extracting gold, silver, lead, zinc, and copper. The mining complex of ‘Cassandra’ in Halkidiki includes the modern gold, silver, lead, and zinc-producing Olympias mine, a world-class gold and copper project, which is under development, a state-of-the-art dry tailings facility, port and storage facilities, and the ‘Black Stones’ mine, which has been under maintenance since late 2021.

The sustainability strategy of Hellas Gold is based on four key pillars: Safe and innovative production activity without exclusions, Responsible production, Prosperity and participation of the local communities, and Healthy natural environment in the present and future. Because mining and gold metallurgy are known to pose significant environmental threats, specific targets have been set for managing waste and wastewater, water resources, and minimizing land disturbance. Overall, 13 environmental quality parameters are monitored at 500 measurement points.

Since 2013, Hellas Gold has issued annual sustainability reports at the GRI core level following the guidelines of the ‘Sustainability Reporting Standards’ edition 2016 of GRI and the ‘Reporting Standards for the Extractives & Minerals Processing Sector, Metals & Mining Industry’ edition 2018-10 of the Sustainability Accounting Standards Board. Moreover, it now compiles quarterly social performance reports and annual CSR and social impact reports (Hellas Gold, 2024). In 2023, Hellas Gold completed its first verification against the Mining Association of Canada’s Towards Sustainable Mining (MAC TSM) protocols for Olympias mine. They achieved the highest rating (AAA) across all indicators for ‘Tailings Management’ and ‘Biodiversity Conservation Management’ and met all TSM ‘Yes’ requirements (Mining Association of Canada, 2024).

4. Conclusion

Based on the above, it is concluded that the ESG disclosures of the four companies examined exhibit many similarities: (i) all follow the GRI guidelines, (ii) they further conform to specific guidelines published by various sectoral organizations, (iii) they set targets and make efforts to improve their carbon footprint, (iv) they leverage disclosures to enhance their external orientation and improve relationships with stakeholders. It was also found that all companies are working towards rehabilitating their mining and quarrying sites. However, the companies that concurrently engage in other productive activities alongside mining use only a few sustainable development indicators directly linked to mining.

5. Acknowledgment

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6. References

Mining Association of Canda (2024). Eldorado Gold. Retrieved 6 May 2024 from: https://mining.ca/companies/eldorado-gold/

GRI. (2024). The global standards for sustainability impacts. Retrieved 2 May 2024 from: https://www.globalreporting.org/standards/

Hellas Gold. (2024). Sustainability. Retrieved 2 May 2024 from: https://www.hellas-gold.com/en/sustainability

Maybee, B., Lilford, E. and Hitch, M. (2023). Environmental, Social and Governance (ESG) risk, uncertainty, and the mining life cycle. The Extractive Industries and Society, 14: 101244.

Mytilineos Energy & Metals (2024). Sustainability. Retrieved 2 May 2024 from: https://www.mytilineos.com/sustainability/sustainability/

Public Power Corporation (2024). Sustainable development. Retrieved 2 May 2024 from: https://www.ppcgroup.com/en/sustainable-development/

Titan Cement Group (2024). Sustainability. Retrieved 2 May 2024 from: https://www.titan-cement.com/sustainability/

Verrier, B., Smith, C., Yahyaei, M., Ziemski, M., Forbes, G., Witt, K. and Azadi, M. (2022). Beyond the social license to operate: Whole system approaches for a socially responsible mining industry. Energy Research & Social Science. 83: 102343.

UNEP (2020). Sustainability Reporting in the Mining Sector: Current Status and Future Trends. United Nations Environmental Programme. 114p.

UNGC (2024). Impact story. United Nations Global Compact. Retrieved 2 May 2024 from: https://unglobalcompact.org/

Environmental, Social and Governance (ESG) Reporting in the South African Mining Industry

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1. Introduction

The mining industry is a significant contributor to the global economy and the economies of many countries. However, the industry is associated with several negative environmental impacts such as air, water, and land pollution. Moreover, the industry extracts non-renewable mineral resources. All these factors make the industry generally considered an unsustainable industry. Over the past decade, pressure has been increasing for the industry to improve its environmental, social, and environmental (ESG) performance. In response to the pressure mining companies have started to report their ESG performance mainly with an aim to obtain their social licenses to operate.

The South African Environmental, Social and Governance Committee (SAMESG) (2017 p.14) defines environmental issues as issues "relating to the quality and functioning of the natural environment and natural systems". These include biodiversity loss; greenhouse gas (GHG) emissions; climate change; renewable energy; energy efficiency; air, water; land; waste management; stratospheric ozone depletion among others. Social issues relate to the rights, well-being, and interests of people and communities. These include human rights; labour; child, slave, and bonded labour; workplace health and safety; human capital management and employee relations; diversity; relations with local communities among others (SAMESG, 2017 p.14). Governance issues relates to the governance of companies including issues such as board structure, size, diversity, skills and independence; executive pay; shareholder rights; stakeholder interaction; disclosure of information; business ethics; bribery and corruption; internal controls and risk management; and, in general, issues dealing with the relationship between a company's management, its board, and its other stakeholders (SAMESG, 2017 p.14).

ESG performance and reporting have become a critical part of the mining industry. The aim is for mining to be done in a way that protects the environment, invests meaningfully in host communities, and adhere to the highest ethical standards during mining operations. This requires companies to develop and integrate ESG strategies with their strategic mine planning and subsequently allocate capital to achieve those strategies. The aim of this paper was to identify the common ESG metrics reported by mining companies in South Africa and analyse the extent to which the companies report these metrics.

2. Methodology

The top four mining companies by market capitalization in South African were selected for analysis and assumed as a proxy of the South African mining industry. According to Statista (2022), these are Anglo American Platinum, Kumba Iron Ore, Impala Platinum (Impala), Gold Fields, and SibanyeStillwater. Since both Anglo-American Platinum and Kumba Iron Ore are owned by Anglo American, in this paper they were considered as one company (Anglo American Plc). Therefore, the

5th ranked company, Sibanye-Stillwater was also considered in the analyses as the 4th ranked company. Annual reports for the companies were analysed to identify the ESG metric reported by the companies for the financial year 2022.

3. Analysis of selected companies

Table 1 shows a summary of the identified ESG metrics reported by the selected mining companies. Because of the diverse commodities produced by the companies and the differences in the companies' sizes, the actual metric values were not recorded in the table. A tick in the table indicates that a particular metric was reported by the company.

The table shows that all the companies under analysis have integrated ESG into their core activities and reporting. The findings are briefly discussed in the following subsections under each ESG category.

3.1 Environment performance

South Africa is a signatory to the Paris Agreement which is a legally binding international treaty on climate change (Republic of South Africa, 2021). As such, all the selected mining companies have aligned their ESG targets to the country's Nationally Determined Contributions (NDCs) 2025 and 2030 GHG emission targets. For example, Anglo and Gold Fields have set targets to improve energy efficiency and reduce GHG emissions by 30% in 2030 (Anglo American, 2022; Gold Fields, 2022). Anglo aims to reduce Scope 3 emissions by 50% by 2040. All companies aim to be carbon neutral for Scope 1 and Scope 2 emissions by 2050 in alignment to South Africa's NDC. Scope 1 emissions are emissions that directly occur from sources that are owned or controlled by a company, Scope 2 emissions occur from the generation of purchased electricity consumed by the company (World Business Council for Sustainable Development (WBCSD) and World Resources Institute (WRI), 2004). Scope 3 emissions or other indirect emissions are as a result of the activities of the company but occur from sources not owned or controlled by the company (WBCSD and WRI, 2004).

It was also found that the analysed companies have established several strategies to ensure the NDC emission targets will be achieved. This demonstrates a commitment by the companies to achieve their ESG performance. For example, Impala Platinum (2022) indicated that the company has developed water, tailings management, energy and decarbonization, and the rehabilitation, mine closure & biodiversity policies. One of the ways Anglo plans to reduce its GHG emissions is by using hydrogen fuel cell-powered vehicles in its operations. Gold Fields plans to achieve net-zero emissions by 2050 through employing energy-efficient initiatives, and by gradually replacing diesel-powered equipment with zero-emission equipment. The company obtained 14% of its electricity from renewable sources in 2022 with a plan to increase to approximately 70% by 2030 and 100% by 2050 (Gold Fields, 2022). It is on track to achieve its target.

Gold Fields plans to recycle 80% of total water used by 2020, achieving 75% and reducing freshwater withdrawal by 45% in 2030. Anglo aims to reduce the withdrawal of fresh water by 50% in waterscarce areas against its 2015 baseline. In terms of tailings management, all companies mentioned that they comply with Global Industry Standard on Tailings Management (GISTM). In terms of biodiversity, all companies aim to minimize biodiversity loss to wildlife, economic activities, and people who depend on natural resources due to their mining activities. Therefore, they report on their operations' impacts and conduct biomonitoring and environmental incident reporting. In general, it was found that the analysed companies report in detail their environmental performance.

Table 1. Summary of identified ESG metrics reported by the selected mining companies (Anglo American, 2022; Impala Platinum, 2022; Gold Fields, 2022; Sibanye Stillwater, 2022)

Category	Metric	Unit	Anglo	Impala	Gold Fields	Sibanye Stillwater
Environment	**Climate change**					
	GHG emissions Scope 1, 2 & 3	Co2e tonnes	✓	✓	✓	✓
	Total energy consumed	Joules/tonne milled	✓	✓	✓	✓
	Environmental incidents (L4 and L5)	Number of incidents	✓	✓	✓	✓
	Renewable energy	% of total energy spend	✓	✓	✓	✓
	Water management					
	Withdrawal of fresh water	m^3/litres	✓	✓	✓	✓
	Water recycled or reused	% of total water used	✓	✓	✓	✓
	Tailings management					
	Tailings storage facilities (TSFs)	Number of TSFs	✓	✓	✓	✓
	Biodivesity					
	Land disturbed by mining activities	Hectares	✓	✓	x	✓
	Land rehabilitated	Hectares	✓	✓	x	✓
Social	**Wellbeing of employees**					
	Fatalities	Number of fatalities	✓	✓	✓	✓
	LTIs	Number of LTIs	✓	✓	✓	✓
	LTIFR	Number of LTIFR	✓	✓	✓	✓
	Communities					
	Health and well-being of host communities		✓	✓	✓	✓
	Investment in host community projects	US$ million US$ million	✓	✓	✓	✓
	Job creation around host communities	US$ million	✓	✓	✓	✓
	Procurement from local communities	US$ million	✓	✓	✓	✓
	Human rights	US$ million	✓	✓	✓	✓
Governance	Board diversity and structure		✓	✓	✓	✓
	Stakeholder engagement		✓	✓	✓	✓
	Policy advocacy		✓	✓	✓	✓
	Ethical culture		✓	✓	✓	✓
	Female representation)	% of workforce	✓	✓	✓	✓

3.2 Social performance

Two common metrics are investments in host communities and safety, health, wellbeing of employees. All the analysed companies report their achievement in this ESG area with significant contributions to their host communities in various way including jobs supported off site, local procurement spend, money distributed to stakeholders, HIV/Aids awareness training and community, education and skills development among others. Like the environmental category companies also set targets to achieve their social performance. For example, Gold Fields plans to achieve 30% of total value creation for host communities and has set a target of having a 30% female workforce by 2030 (Gold Fields, 2022).

Anglo plans to achieve Sustainable Development Goal (SDG) 3 health targets in host communities, schools in host communities to perform within the top 20% of state schools nationally and five jobs supported off site for every job on site (Anglo American, 2022) by 2030. In terms of safety, it has always been the goal of every mining company to achieve zero harm to employees and mining companies have always reported this metric for several years now. It can be concluded that because social issues have direct implications on mining companies' social license to operate, these are extensively reported by the companies selected.

3.3 Governance performance

In relation to ESG matters, governance refers to how climate-related issues are integrated into a company's processes through its governance mechanisms and the role played by the company's board of directors (board) in overseeing climate issues (Johannesburg Stock Exchange, 2022). Because governance is a process of how a company practices its business and not an outcome it is difficult to quantify governance performance numerically. Nonetheless, it was found that all companies report on their board diversity and structure, executive salaries, anti-bribery and anti-corruption, audit and assurance, stakeholder engagement, regulatory compliance, internal committees, and policies among other governance metrics. Notably, all companies mentioned their board's oversight of climaterelated impacts, risks, and opportunities, and their strategies for integrating sustainability issues into the overall governance. One way that mining companies demonstrate ESG governance is by subscribing to international ESG-related standards. Table 2 shows the common international standards the selected mining companies subscribe to. A tick in the table indicates that the company was found that it subscribes/is a member or signatory to the standard and vice versa for a cross.

The analysed companies subscribe to the commonly available guidelines and standards as shown in Table 2. The subscriptions are a demonstration of the companies' commitment to sustainability; for example, being a signatory to the Paris Agreement. One of the aims of the Paris Agreement is to limit the global warming temperature rise to well-below 2°C and pursue efforts to limit it further to 1. 5°C (Republic of South Africa, 2021). Anglo American and Gold Fields signed a Paris Pledge for Action demonstrating the companies' commitment to the Paris Climate Agreement (Anglo American, 2022; Gold Fields, 2022). As evidence to the companies' commitment to good ESG performance, the companies analysed received different international disclosure recognitions for their achievements. For example, Impala had an 'A' MSCI ESG ratings in 2022 (Impala Platinum, 2022). The other measure is companies integrating climate change (ESG) issues at a corporate board level. Sibanye Stillwater developed two policies namely the ESG policy and the tailings stewardship policy and also subscribe to ISO 14001: 2015 (environmental management standard); Biodiversity Disclosure Project; ICMM; IRMA; UN SDGs; WGC; International Cyanide Management Code and many other legislations applicable in countries they operate (Sibanye Stillwater, 2022).

Table 2. Reporting guidelines and standards (Anglo American, 2022; Impala Platinum, 2022; Gold Fields, 2022; Sibanye Stillwater, 2022)

Reporting guideline/standard	Anglo	Impala	Gold Fields	Sibanye
The Global Reporting Initiative (GRI)	✓	✓	✓	✓
The Carbon Disclosure Project (CDP)	X	✓	✓	✓
The United Nations Global Compact (UNGC)	✓	✓	✓	✓
The Equator Principles	X	X	X	X
International Organization for Standardization (ISO)	✓	✓	✓	✓
International Council on Mining and Metals (ICMM)	✓	✓	✓	✓
Extractive Industry Transparency Initiative (EITI)	✓	X	X	✓
Initiative for Responsible Mining Assurance (IRMA)	✓	✓	X	✓
Task Force on Climate-related Financial Disclosures (TCFD)	✓	✓	✓	✓
JSE Sustainability and Climate Change Disclosure Guidance	X	✓	✓	X
South African guideline for the reporting of environmental, social and governance parameters (SAMESG)	X	X	X	X

4. Conclusions

All companies analysed have incorporated ESG performance into their strategic plans with a common timeframe of 2030 and 2050 to achieve set performance targets. There are more environmental metrics that companies report on compared to social and governance metrics. This maybe because environmental performance metrics are based on physical quantities of impacts compared to governance and social performance and hence are easier to measure. However, unlike financial reporting where there is consistency and comparability, no equivalent international standard is available yet for the reporting of ESG performance. This makes identifying good or bad performance and comparison with other companies difficult. Like IFRS standards, a standard reporting system and metrics to track performance against ESG targets and requirements are needed for the mining industry if mining companies are to implement ESG best practices. As existing global standards evolve and coalesce, and as industries continue to embrace and enhance ESG reporting it is expected that ESG performance and reporting will also improve.

5. Disclaimer

The opinions, omissions, and interpretations expressed in this paper are those of the author only and not attributed to the companies analysed.

6. References

Anglo American (2022). Sustainability Report 2022. Retrieved from: https://www.angloamerican.com/~/media/Files/A/Anglo-American-Groupv5/PLC/investors/annual-reporting/2022/Sustainability-Report-2022.pdf

Gold Fields Limited (2022). Integrated Annual Report 2022. Retrieved from: https://www.goldfields.com/pdf/investors/integrated-annual-reports/2022/iar-2022-full-new.pdf

Impala Platinum (2022). 2022 ESG Report: Supplement to the 2022 Annual Integrated Report. Retrieved from: https://www.implats-ir.co.za/reports/implats-iar-2022/pdf/ESG-spreads.pdf

Johannesburg Stock Exchange (2022). JSE's Sustainability and Climate Disclosure Guidance. Retrieved from: https://group.jse.co.za/jses-sustainability-and-climate-disclosure-guidance

Republic of South Africa (2021). South Africa first nationally determined contribution under the Paris Agreement.

Sibanye Stillwater (2022). Integrated report for the year ended 2022. Retrieved from: https://reports.sibanyestillwater.com/2022/download/ssw-IR22.pdf?v=20231205

Statista (2022). Market capitalization of the leading mining companies in South Africa in 2023. Retrieved from: https://www.statista.com/statistics/1014904/south-africa-leading-mining-companies/

SAMESG (2017). The South African guideline for the reporting of environmental, social and governance parameters within the solid minerals and oil and gas industries. The SAMESG Guideline, 2017. The South African Environmental, Social and Governance Committee. Retrieved from: https://www.samcode.co.za/samcode-ssc/samesg

United Nations Development Programme (2023). What are the Sustainable Development Goals? Retrieved from: https://www.undp.org/sustainable-development-goals

Research Study on Social Licence to Operate for the Future Phosphate Mining in North-East Estonia

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Keywords: Phosphorite, ESG risks, SLO - Social Licence to Operate

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Abstract

Today, raw materials have become essential in the manufacturing of common goods and technologies we use every day. Readily accessible raw materials are critical to EU industries and the continued growth of the European economy. This growth has resulted in an economy that is heavily reliant on raw materials, many of which need to be more sustainable and need to be sourced from regions outside the EU. The EU has determined that 34 individual raw materials have been deemed critical for Europe. Phosphorite rock is listed on the CRM list. Estonia has significant phosphate rock reserves within the EU, and their extraction and processing in Estonia have been sensitive issues in the past.

Last year's research on identifying and understanding the most critical Environmental Social Governance (ESG) risks for any potential phosphorite mining and processing by compiling and analysing the opinions of Estonian mining experts and finding similarities and differences between the perceptions of mining experts and wider society groups.

The results of the research show that assessments of the importance of risks are multifaceted, being different among different interest groups. For example, mining experts assessed governance risks as more essential and social risks as less critical, leaving environmental risks in the middle and earning a profit risk, which got the highest score. Comparison with other stakeholders from the research reveals that governance risks are most important for mining experts, but environmental risks are most important for other stakeholders.

Currently, the Estonian Geological Survey is running a government-funded research program to make a feasibility study in the pre-selected area. The end of this research will give a major understanding of how Estonia can move forward with larger plans for the Estonian phosphorite rock deposit. Important is to understand the ESG risk in future mining projects of phosphorite rock.

Circular Economy & Waste Reuse

Exploring New Sustainable Horizons in the Mining Industry: Circular Economy, Sustainability and Technological Development

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Keywords: Circular economy, mining wastes, sustainability, mining of the future

Abstract

The challenge facing the mining industry to achieve carbon neutrality in its operations soon and become a sustainable sector is getting closer and closer. With this, efforts are intensifying to find new materials that can totally or partially replace those that are traditionally exploited, using CO2 capture methods, replacing traditional fossil fuels with alternative fuels and increasing efficiency in the production process, as well as seeking new uses and opportunities for traditional materials and their wastes by developing materials that are increasingly durable over time, among other impact measures.

In line with this objective and according to the needs exposed in the industry, the School of Mines of the Universidad Nacional de Colombia through the research groups of Cement and Construction Materials (CEMATCO) and the IGNEA Observatory, recognize the importance of promoting the development of projects focused on the circular economy within the mining industry, within the framework of environmental sustainability.

The objective is based on promoting the adoption of circular practices in mining by identifying opportunities to reduce waste or generate new products from it, reuse materials and optimize extraction and production processes. Through research and collaboration with different actors in the sector, we seek to generate innovative solutions that contribute to minimizing the environmental impact of mining and preserving natural resources.

The potential of the circular economy is considered fundamental to positively transform the mining industry and thus encourage its implementation through projects that boost sustainability and promote a responsible and efficient approach in the use of resources.

Development of new products from the remaining material of the municipal solid waste (MSW) incineration process used in the production of electricity on the island of San Andres, Colombia.

The island of San Andres, located in the archipelago of San Andres, Providencia and Santa Catalina - Colombia, currently generates about 25,000 tons of solid waste per year, which are disposed of in the Magic Garden landfill. This landfill reached its maximum permitted capacity in 2019, being necessary to carry out several impact actions among which are the expansion and adaptation of new disposal areas and the construction of an energy generation plant from the incineration of municipal solid waste. The energy generation plant has been a good step in MSW management at the isa; it has the capacity to process between 80 and 100 tons of solid waste per day, generating approximately 8

tons per day of industrial by-products such as ash, slag, and calcium salts. Although these materials can be disposed of in sanitary landfills after analysis of toxicity and contaminating elements, their potential use in the construction industry can contribute to several of the sustainable development objectives established by the United Nations, and of course to the development of the island's infrastructure. Knowledge and technical research on the physicochemical and mineralogical characteristics of by-products, their effects when added as filler or active additions to concrete, or their use as recycled aggregates in concrete are null. Therefore, this research aims to better understand these materials through a detailed characterization, and to propose a use in the construction industry based on their effects when added in mortars or concrete, and in the current infrastructure needs of the island, and thus contribute to the sustainable development not only of the island of San Andres but of the entire archipelago and the region.

Valorization of sand washing sludge waste from an aggregate plant: evaluation as a supplementary cementitious material.

The reuse and reincorporation of waste generated in production processes is becoming increasingly important in the world, due to the double effect it has in terms of sustainability. The first is the environmental factor, since the impact generated is reduced by reducing the amount of waste. The second is the financial factor, since new products are developed that companies did not have initially, generating financial profitability. Therefore, this research evaluates the possible reuse of waste from gravel and sand washing sludge from an aggregate plant as Supplementary Cementitious Material (SCA) after being thermally activated, seeking to promote the circular economy in the construction materials sector. The physical, chemical and mineralogical characterization of the residue is presented and its pozzolanic activity was evaluated by means of the SAI (Strength Activity Index). It was found that, despite its low clay mineral content, the thermally activated residue performed very well as SCM with SAI between 81 and 106 with a tendency to increase with the age of curing. This shows that it can be a very promising potential use for this type of waste.

Uncalcined compacted waste from the washing of gravels and sands sludge from an aggregate plant as a waste valorization strategy.

The management of fine quarry waste has commonly been the final disposal in mine tailings and as filler material for landscape recovery in already exploited areas. However, different uses of these wastes have been studied, highlighting earth constructions, since a new economic benefit is generated and the environmental impact is reduced. In addition, compared to cement constructions, earth constructions are environmentally friendly and represent an energy saving, due to their low CO2 emissions due to the low or null cement content in their manufacture, as well as the good physical and mechanical properties obtained.

Thus, this work evaluated the use of waste sludge from an aggregate plant (resulting from the crushing and washing process) as a circular economy strategy. The raw materials were characterized chemically, mineralogically and physically and were used in the preparation of cubic specimens of uncalcined material, which were hydraulically compacted in metal molds in mixtures of waste sludge, commercial gray cement and washed fine sand. The performance of the cubic specimen was evaluated by testing water absorption and simple compressive strength (SCS). In the best configuration, an increase in SCS of 221.3 % (reaching 8 MPa) was found in 20 % cement samples with respect to the waste only samples and, in turn, an increase of 517.3 % (reaching 15 MPa) when these were cured in water was also found. Thus, wastes mixed with small amounts of cement are promising in the manufacture of compacted adobe (MCA), particularly as masonry or structural elements from uncalcined wastes.

Study of the treatment of recycled concrete aggregates and its impact on the durability of mortars.

The objective of this research was to improve the quality of recycled concrete fine aggregates (RFA), using a treatment based on diammonium hydrogen phosphate (DAP), used commercially as a soil fertilizer. The effect of the DAP treatment on the durability due to carbonation of mortars manufactured with partial and total replacement of treated RFA was investigated. The results show a maximum reduction of water absorption up to 33% in the RFA, using a minimum DAP concentration of 0.5mol/L-7days-20oC, due to a refinement of the pores as a consequence of the formation of calcium phosphates such as hydroxyapatite (HAP). On the other hand, it was evidenced that the carbonation phenomenon does not have a negative effect on the durability of mortars manufactured with DAP-treated RFA, not finding a decrease in the compressive strength of carbonated mortars with respect to non-carbonated mortars, where the carbonation depth of mortars with 100% RFA treated decreased up to 90% and 63% for W/C of 0.45 and 0.50, with respect to mortars with untreated RFA. Likewise, an inversely proportional relationship is found between carbonation rate (Kca) and compressive strength, showing that a greater presence of treated AFR in the mortar promotes an increase in compressive strength and a decrease in carbonation rate, where the closest relationship is found for a 100% substitution of treated AFR, behavior associated with a lower permeability of the cement matrix, as one of the consequences of the microstructural densification obtained by the use of the DAP treatment in the AFR.

Manufacture of non-conventional cements for the improvement of pavements of tertiary roads in the region of Los Llanos, department of Arauca, Colombia.

In the diversification of construction technologies to achieve sustainability, the potential of soil stabilization in different types of engineering uses has been highlighted, so that a functional use can be given to the materials coming from earthworks or excavations. This stabilization process can be physical, mechanical and/or chemical, where in the latter, through the addition of cementitious agents, soil properties are improved, optimizing its mechanical behavior and durability in the face of external agents.

Thus, different types of cementitious agents are currently incorporated, usually ordinary Portland cement and/or lime. Seeking to implement sustainable technologies that take advantage of local resources and waste, while providing eco-efficient solutions to the needs of the most remote regions, this article presents the importance of clay minerals in soil stabilization with alkaline activated cements (AAC) as a sustainable technology, so that the main effects on clayey soils of low plasticity can be identified, which are the ones used in the research project "Manufacture of environmentally friendly cements for the improvement of tertiary road pavements in the Orinoquia region". This article will present the results of the physical, chemical, geotechnical and mineralogical characterization process of the soils and materials used in the manufacture of alkaline activated cement based on rice husk ash and the same thermally activated soil as precursors.

Effect of cement and aggregate substitution in a conventional concrete with activated alkaline cement (AAC) and lightweight aggregates (LWA).

Concrete production has a significant environmental impact, due to the extraction of its raw materials and the manufacture of Ordinary Portland Cement (OPC). Alternative materials such as hybrid cement and recycled polymer aggregate can reduce this detrimental environmental impact. The objective of this research project is to determine the effect on Interfacial Transition Zone (ITZ) porosity and compressive strength of a Light Weight Concrete (LWAC), produced with a hybrid cementitious matrix composed of OPC and Alkaline Activated Cement (AAC) based on fly ash (FA) and an additional source of calcium (Lime). In this project, an experimental design was carried out to identify the proportion of alternative cementitious material and recycled polymer that would provide the highest compressive strength. For this purpose, a compressive strength test was performed at 7 and 28 days of curing. Having the proportions of the alternative materials, a complementary sample was made to evaluate their mechanical performance and to perform a quantitative analysis of the porosity of the ITZ. Finally, the compressive strength and porosity of ITZ were correlated to evaluate the influence of ITZ microstructure on the mechanical properties of LWAC. X-ray diffraction (XRD) and Fourier transform infrared spectroscopy (FTIR) were used to identify the formation of gels due to alkaline activation. The lightweight concrete obtained in this research project could be used to design a concrete structure according to Colombian technical standards for structural design. In that case, it would be possible to reduce the cross section of the elements that compose the structure. Thus, decreasing the dead loads directly related to its own weight. The results also indicated that it is possible to substitute up to 70% of the OPC with alternative cementitious materials. This could ultimately translate into savings in the total cost of the work and, with the use of FA and lime, a reduction in CO_2 emissions.

Microstructural development and its impact on the compressive strength and absorption of compressed earth blocks stabilized with alternative cements and construction and demolition waste.

The consolidation of the transition to sustainability implies thinking the life cycle under principles of energy efficiency and transition to circularity, so that low embedded energy building materials that incorporate waste are a means to ensure this transformation of processes and products. Construction and demolition waste (CDW) is one of the main solid wastes generated, having different types of them such as soil from earthworks, concrete demolition waste, masonry, wood, among others. Finding a use for the utilization would contribute to optimize the waste management while becoming inputs for new materials, being this the main object of study to analyze the potential use of waste in stabilized earth-based materials. This research focuses on the study of stabilized soils (soil) for engineering uses, particularly in compressed earth blocks (CEB) incorporating waste and alternative cements, under an approach of analyzing the microstructural changes and their incidence on performance, when varying the types and amount of cement and the proportions of RCA. Excavation soils and recycled concrete fine aggregates stabilized with a commercial Portland cement as a control, and with alternative cements such as an LC3 type (Limestone Calcined Clay Cement) and an alkaline activated cement will be used. The study consists of an analysis of soil-based mixes for the different types of cement, developed under an experimental mix design to determine the trend of mechanical strength. Different mix levels are analyzed to recognize the behavior of water in the mix and its effect on absorption, identifying them geotechnically and mineralogically; and the best mixes will undergo microstructural characterization to know the main components present and the details of the porosity and uniformity of the matrix. Understanding the behavior of microstructural and mineralogical changes can highlight the relevance of the factors that condition the performance of mixtures of building materials with earth, such as rammed earth or BTC; therefore, deepening the knowledge of these phenomena contributes to strengthening the use of alternative building materials that respond to the needs of a shift towards sustainability and that are developed to have less embedded energy and incorporate waste.

References

Alujas, A., Fernández, R., Martirena, J.F. and Quintana, R. (2010). Empleo de arcillas caoliníticas de bajo grado activadas térmicamente como una alternativa para el reemplazo parcial de cemento Pórtland. Lab. Mater. Constr. Ec. Polytech. Fed. Lausanne. 40(4): 1–10.

Damineli, B.L., Kemeid, F.M., Aguiar, P.S. and John, V.M. (2010). Measuring the eco-efficiency of cement use. Cem. Concr. Compos. 32(8): 555–562.

Damtoft, J.S., Lukasik, J., Herfort, D., Sorrentino, D. and Gartner, E.M. (2008). Sustainable development and climate change initiatives. Cem. Concr. Res. 38(2): 115–127.

Kula, I., Olgun, A., Sevinc, V. and Erdogan, Y. (2002). An investigation on the use of tincal ore waste, fly ash, and coal bottom ash as Portland cement replacement materials. Cem. Concr. Res. 32(2): 227–232.

Paris, J.M., Roessler, J.G., Ferraro, C.C., DeFord, H.D. and Townsend, T.G. (2016). A review of waste products utilized as supplements to Portland cement in concrete. J. Clean. Prod. 121: 1–18.

Payá, J., Monzó, J., Borrachero, M., Serna, P., Velázquez, S. and Ordonez, L. (2002). El factor de eficacia cementante de puzolanas silíceas y silicoaluminosas muy reactivas. VII Congr. Nac. Propiedades Mecánicas Sólidos. pp. 591–600.

Portal, T.S. (2024). Major countries in worldwide cement production from 2011 to 2016 (in million metric tons). Retrieved from: https://www.statista.com/statistics/267364/world-cement-production-by-country/

Restrepo, J.C., Restrepo-Baena, O.J. and Tobón, J.I. (2013). Reducción de CO_2 en la Industria Cementera por Medio de Procesos. Rev. Colomb. Mater. 5: 54–60.

Shi, C. and Qian, J. (2000). High performance cementing materials from industrial slags - a review. Resour. Conserv. Recycl. 29(3): 195–207.

Uchima, J.S., Restrepo-Baena, O.J. and Tobón, J.I. (2015). Pozzolanicity of the material obtained in the simultaneous calcination of biomass and kaolinitic clay. Constr. Build. Mater. 95: 414–420.

Uchima, J.S., Restrepo-Baena, O.J. and Tobón, J.I. (2016). Mineralogical evolution of portland cement blended with metakaolin obtained in simultaneous calcination of kaolinitic clay and rice husk. Constr. Build. Mater. 118: 286–293.

Green Chemistry in Metal Supply Chains and Circular Economy

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1. Introduction

The significance of critical and strategic minerals like cobalt (Co), nickel (Ni), and rare earth elements (REE) majorly stems from the development of clean energy technologies like the electrification of vehicles. The global demand for these metals is expected to increase in the upcoming years due to the advancement in modern technologies (Australian Government, 2019). Moreover, the geographical concentration of cobalt production in DRC and the socio-political instability of the country have created a shortage of supply across the globe (Beatty et al., 2019; Mudd et al., 2013; Shedd, Mccullough, and Bleiwas, 2017; Watari, Nansai, and Nakajima, 2020). Similarly, nickel faces supply constraints due to market dynamics in Indonesia (Lim, et al., 2021; Wang et al., 2023), while the rare earth market is dominated by the Chinese government's monopolistic control (Barakos, et al., 2022).

To ensure a continuous supply of these elements to the global market, processing from an alternative source to the primary ore deposit is necessary. To combat this situation, a new aspect towards mining, namely, technospheric mining, is to be considered. Technospheric mining is an umbrella term encompassing the extraction of valuable products from anthropogenic waste materials (Johansson et al., 2013; Lim and Alorro, 2021). Extraction from end-of-life products and wastes produced in the mining industry, like tailings, slag, and industrial byproducts, would complement the traditional production process (Arndt et al., 2017) and mitigate any geopolitical risks associated with the supply chain of a given commodity. Moreover, extracting from mine wastes reduces the volume of net waste generated and reduces the dependence on primary ore resources (Arndt et al., 2017). With the increasing demand for natural resources, it is evident that this technique would substantially contribute to supporting the primary mineral resources.

As the demand for critical and strategic metals continues to increase, along with growing environmental concerns, there is a need to prioritise a cleaner and more efficient processing route for these elements. This is where the principles of green chemistry become crucial. Green chemistry focuses on principles that help protect the economy, society, and the environment. They encompass strategies such as utilising sustainable materials, reducing waste generation, and planning for responsible disposal of products at their end-of-life stage (Anastas and Warner, 1998). These principles encourage scientists and engineers to find innovative ways to minimise waste, conserve energy, and replace hazardous substances (Anastas and Warner, 1998).

Adopting certain principles of green chemistry, such as utilising green chemicals like organic compounds, repurposing wastes, and designing benign processes for processing these elements, would aid in sustainability and building a circular economy. To illustrate this concept in the processing industry, quite a few studies have been conducted on extracting critical and strategic metals from primary and secondary wastes using green solvents. This study will focus on extracting cobalt, nickel, and rare earth elements from secondary sources.

Table 1 shows that combining the principle of green chemistry and circular economy is possible and paves the way for more sustainable industrial practices. Our ongoing research aims to extract rare earth elements from acid-crack leach tailings. Another research focuses on extracting cobalt and nickel from nickel furnace slag using organic acids. The study includes a comparison of the behaviour of ore and leach tailings to discern variations in reactivity while also examining how processing from wastes like slag differs from conventional ore processing. The results obtained are given below.

Table 1: Literature sources for green chemistry

Reference	Source/Feed	Experimental Conditions/Parameters	Elemental Recovery %
(Meshram et al., 2020)	Copper Converter Slag	2N Citric Acid, Particle size: <45 µm, Pulp Density: 15%, 35 °C, 9–10 h	Co – 94% Ni – 89% Cu –99.1%
(Lim et al., 2023)	Nickel Furnace Slag	1 mol/L Citric Acid, 0.5% (v/v) Hydrogen Peroxide, Particle size: -100 +75µm, Pulp density: 2.5%, 400 rpm, 60°C, 6 hours	Co - 91.7% Ni - 82%
	Nickel Converter Slag		Co - 99.1% Ni - 65%
(Chen et al., 2021)	Lithium-ion batteries	300 g/L Glycine with 10% H_2O_2, S/IL ratio: 1:100, 70^{o}C, 7 hours	Co - 97.07% Li - 90.95%
(Huang et al., 2023)	Copper Slag	100g/L Glycine, 40^{o}C for 10.5 hours	Cu - 86.4%
(Ji, Li, and Zhang, 2022)	Calcined Coal Coarse Refuse	0.05 mol/L maleic, citric, and oxalic acid, S/L ratio: 1:100, 500 rpm, 75^{o}C, 2 hours	REE – 50 – 60 %
(Gergoric et al., 2018)	NdFeB magnet powders	1 mol/L acetic acid and 1 mol/L citric acid S:L ratio at 1/50,400 rpm, 25 ± 1 °C, 24 h	REE > 95%

2. Materials and Methods

The leaching reagents used in this study were 100% oxalic acid dihydrate (C2H2O4. 2H2O) (Sigma Companies Group Pty Ltd, Australia), 100% pure L-ascorbic acid ($C6H8O6$) (Daintree Quality Herbs, USA) and 100% anhydrous citric acid ($C6H8O7$) (Sigma Group Companies Pty Ltd, Australia) in a solid crystalline form.

Batch leaching experiments were conducted using a three-necked round-bottom flask. The flask was fitted with a condenser on one neck and a thermometer on the other to monitor the temperature. An overhead stirrer with a collapsible impeller was fitted to ensure mixing and was set to rotate at a fixed speed of 250 rpm. The effect of variables influencing the leaching process, such as particle size, reaction temperature, and time, were investigated. It was placed in a heating mantle to achieve and maintain the desired reaction temperature during leaching. Once the desired temperature was attained, the feed was weighed and added to the flask. A solid-to-liquid ratio of 1:10 was maintained. Solution samples were collected at frequent intervals. The collected samples were centrifuged and vacuum-filtered using a prefilter. The concentration of the elements in the dissolved solution was determined using an Inductively Coupled Plasma – Optical Emission Spectroscopy (Agilent 5100 Synchronous Vertical View-SVDV).

3. Results and Discussion

3.1 Rare Earth Element Extraction from Acid-Crack Leach Tailings

The composition of the ore and ACL tailings are given in Table 2 for context.

Table 2. Elemental Composition of Ore and ACL Tailings

Elements (%)	T-REE	Al	Ca	Fe	P	Th
Ore	6.94	1.75	0.37	35.80	2.41	0.22
Acid-Crack Leach Tails	2.79	2.42	1.63	20.70	8.16	0.2

The feeds were subjected to an oxalic acid leach. Figure 1 shows a comparison of the behaviour of the ore and ACL tailings in 0.57 mol/L oxalic acid.

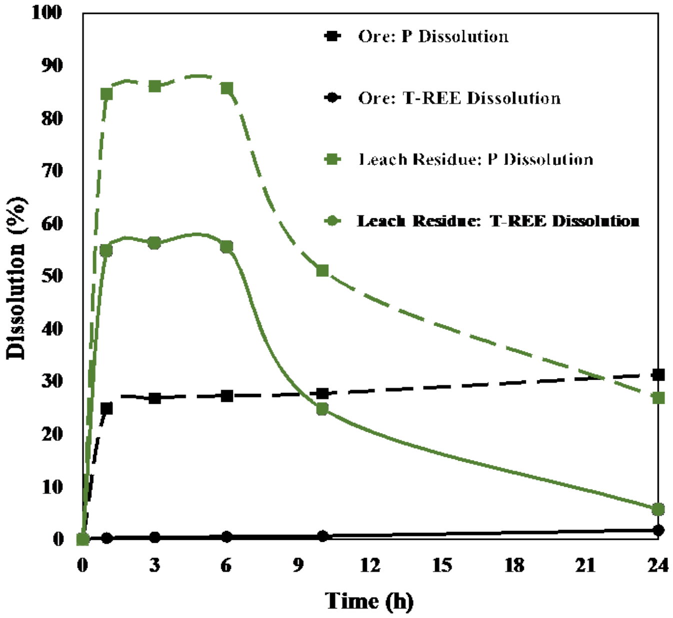

Figure 1. Comparison of Oxalic Acid Leach Behaviour of ACL tailings and Ore (0.57 mol/L oxalic acid, S/L ratio = 1:10, 250 rpm)

The ore shows a linear phosphorus dissolution in oxalic acid, gradually increasing over the 24-hour period (Yamini and Dyer, 2023). Also, there was very minimal rare earth element dissolution. In the case of ACL tailings, a maximum dissolution was achieved within the first hour. The recovery stayed constant over the 6 hours and dropped after 10 hours. It is to be noted that the REE follows the same trend as phosphorus, unlike the ore behaviour.

3.2 Cobalt and Nickel Extraction from Nickel Furnace Slag

The nickel furnace slag was subjected to a citric and ascorbic acid leach. The composition of the nickel furnace slag is given in Table 3. Ascorbic and citric acids have been abbreviated to AA and CA, respectively.

Table 3. Elemental Composition of Nickel Furnace Slag

Elements	Fe	Ni	Co	Si
Composition (%)	40.7	0.6	0.2	15.9

Figure 2 shows the leaching behaviour of nickel furnace slag with ascorbic acid, citric acid, and the synergistic system.

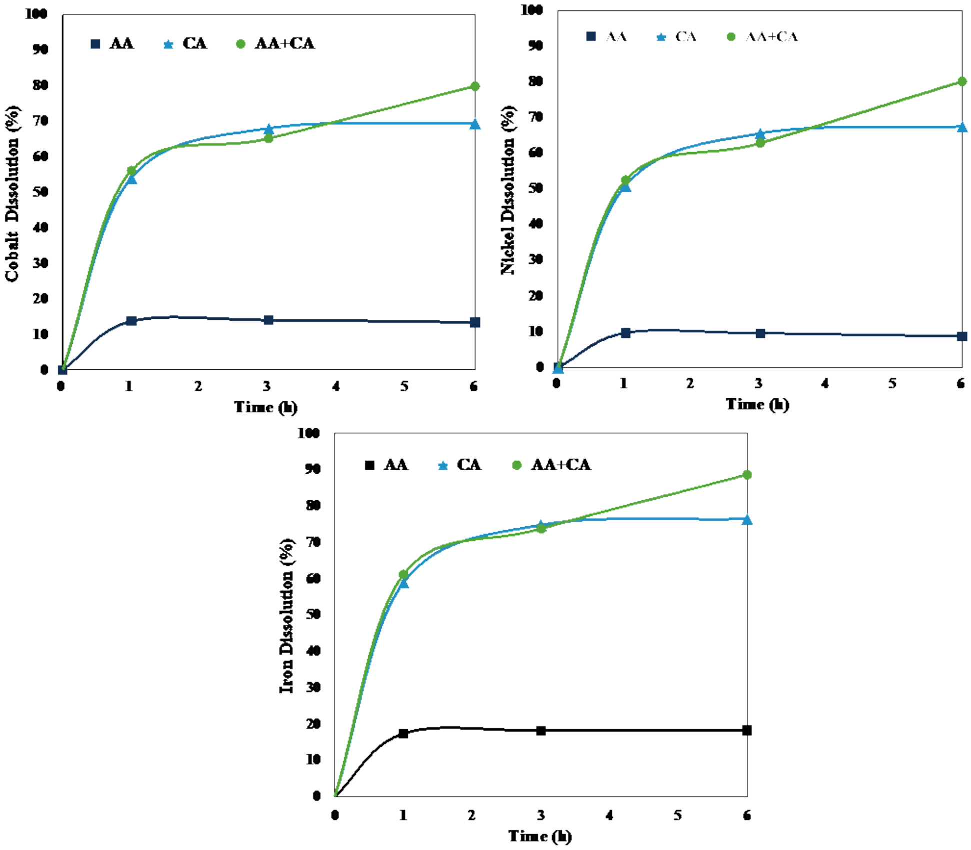

Figure 2. Leach behaviour of Nickel Furnace Slag in individual organic acids and the synergistic system (80°C, 0.5 M AA, 0.5 M CA. 0.5 M AA+CA, particle size = 34 microns, stirring speed = 250 rpm)

It is clearly seen that the synergistic system performs better than the individual systems. This is because citric acid, a strong leaching reagent, leaches the cobalt, nickel, and iron on the surface and converts them into their corresponding metal salts (Meshram et al., 2020). Meanwhile, ascorbic acid, a strong reducing agent, reduces the slag matrix (Li et al. 2012). This helps in leaching the cobalt and nickel trapped in the slag matrix. The increased iron recovery is due to the reduction of the slag matrix. Moreover, adopting the synergistic approach in ores is rare. This indicates that a different approach is needed when processing primary and secondary waste materials.

4. Conclusion

The studies conducted demonstrate that we can achieve significant recoveries from processing wastes using green chemistry principles. Despite the low elemental percentages in these wastes, the large volume of material processed makes this approach advantageous. Since the material is already ground and handled, further processing of this stream is relatively easy. Despite less favourable economics, the increasing demand for critical minerals and the drive for sustainability make this approach more attractive than ever. Reprocessing mining wastes, such as slag and tailings, using green solvents helps reduce the ecological footprint associated with processing. This approach also demonstrates that reprocessing can seamlessly be integrated into various conventional processing flowsheets. This adaptability supports the evolving industrial demands for more sustainable solutions and contributes to building a circular economy.

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6. References

Arndt, N.T., Fontboté, L., Hedenquist, J.W., Kesler, S.E., Thompson, J.F.H. and Wood, D.G. (2017). Future Global Mineral Resources. Geochemical Perspectives. 6(1): 1–184.

Australian Government (2019). Australia’s Critical Minerals Strategy 2019. Retrieved from: https://www.industry.gov.au/news/australias-critical-minerals-strategy-released

Barakos, G., Dyer, L. and Hitch, M. (2022). The Long Uphill Journey of Australia’s Rare Earth Element Industry: Challenges and Opportunities. International Journal of Mining, Reclamation and Environment. 36(9): 651–70.

Beatty, D., Fu, X., Bustamante, M., Gaustad, G., Babbitt, C., Kirchain, R., Roth, R. and Olivetti, E. (2019). Cobalt Criticality and Availability in the Wake of Increased Electric Vehicle Demand: A Short-Term Scenario Analysis. In Minerals, Metals and Materials Series, 355–357. Springer International Publishing.

Chen, M., Wang, R., Qi, Y., Han, Y., Wang, R., Fu, J., Meng, F., Yi, X., Huang, J. and Shu, J. (2021). Cobalt and Lithium Leaching from Waste Lithium Ion Batteries by Glycine. Journal of Power Sources. 482: 228942.

Gergoric, M., Barrier, A. and Retegan, T. (2019). Recovery of Rare-Earth Elements from Neodymium Magnet Waste Using Glycolic, Maleic, and Ascorbic Acids Followed by Solvent Extraction. Journal of Sustainable Metallurgy. 5(1): 85–96.

Gergoric, M., Ravaux, C., Steenari, B.M., Espegren, F. and Retegan, T. (2018). Leaching and recovery of rare-earth elements from neodymium magnet waste using organic acids. Metals 8(9): 721.

Huang, Y., Wang, D., Liu, H., Fan, G., Peng, W. and Cao, Y. (2023). Selective Complexation Leaching of Copper from Copper Smelting Slag with the Alkaline Glycine Solution: An Effective Recovery Method of Copper from Secondary Resource. Separation and Purification Technology. 326: 124619.

Ji, B., Li, Q. and Zhang, W. (2022). Leaching Recovery of Rare Earth Elements from the Calcination Product of a Coal Coarse Refuse Using Organic Acids. Journal of Rare Earths. 40(2): 318–327.

Johansson, N., Krook, J., Eklund, M. and Berglund, B. (2013). An Integrated Review of Concepts and Initiatives for Mining the Technosphere: Towards a New Taxonomy. Journal of Cleaner Production. 55 :35–44.

Kannappan, Y., and Dyer, L. (2023). Extraction of Rare Earth Elements from Low-Grade Ore and Process Waste Stream. In the proceedings of the 26th World Mining Congress (WMC 2023), 619–29. Brisbane, Australia.

Li, L., Lu, J., Ren, Y., Zhang, X.X., Chen, R.J., Wu, F. And Amine, K. (2012). Ascorbic-Acid-Assisted Recovery of Cobalt and Lithium from Spent Li-Ion Batteries. Journal of Power Sources. 218: 21–27.

Lim, B. and Alorro, R.D. (2021). Technospheric Mining of Mine Wastes: A Review of Applications and Challenges. Sustainable Chemistry. 2(4): 686–706.

Lim, B., Aylmore, M., Grimsey, D. and Alorro, R.D. (2023). Technospheric Mining of Critical and Strategic Metals from Nickel Slag – Leaching with Citric Acid and Hydrogen Peroxide. Hydrometallurgy. 219: 106066.

Lim, B., Kim, H.S. and Park, J. (2021). Implicit Interpretation of Indonesian Export Bans on Lme Nickel Prices: Evidence from the Announcement Effect. Risks. 9(5): 93.

Meshram, P., Prakash, U., Bhagat, L., Abhilash, Zhao, H. and van Hullebusch, E.D. (2020). Processing of Waste Copper Converter Slag Using Organic Acids for Extraction of Copper, Nickel, and Cobalt. Minerals. 10(3): 290.

Mudd, G.M., Weng, Z., Jowitt, S.M., Turnbull, I.D. and Graedel, T.E. (2013). Quantifying the recoverable resources of by-product metals: The case of cobalt. Ore Geology Reviews. 55: 87–98.

Paul, A. and Warner, J. (1998). Green Chemistry: Theory and Practice. Oxford University Press.

Shedd, K.B., Mccullough, E.A. and Bleiwas, D.I. (2017). Global Trends Affecting the Supply Security of Cobalt. Mining Engineering. 69 :37–42.

Takuma, W., Nansai, K. and Nakajima, K. (2020). Review of Critical Metal Dynamics to 2050 for 48 Elements. Resources, Conservation and Recycling. 155: 104669.

Wang, X-Q., Wu, T., Zhong, H. and Su, C-W. (2023). Bubble Behaviors in Nickel Price: What Roles Do Geopolitical Risk and Speculation Play? Resources Policy. 83: 103707.

Pursuing Circularity in Mining – An Overview on State-of-the-art Practices

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1. Introduction

Circular economy, as a concept, pursues a sustainable model of production and consumption. It promotes the sharing, leasing, repairing, refurbishing, and recycling of existing materials and products, with the aim of extending the life cycle of these items as much as possible. Furthermore, the concepts of mining and circularity, are inextricably interconnected as they both can play crucial roles in the production, use, and recycling of raw materials towards a more sustainable use for society. Moreover, the mining industry is not foreign to the concept of circular economy. In recent years several strategies to maximize the use of mine water, re-use and reprocessing of rock waste and tailings, and alternative energy efficient systems to the traditional ones have been focus of research. However, as discussed in the Responsible Mining Leadership Forum 2023 held in England by the International Council on Mining and Metals (ICMM), the processes that currently take part in mining have not been built to support a circular economy. In fact, the previously described efforts are limited to isolated initiatives. Considering the challenges, the mining industry is facing, disruptive technologies, developments, and concepts, such as circularity and circular economy, are changing completely the current way we plan, conduct, and develop mining. According to the framework of circular economy, redesigning products and processes stand for a key component when pursuing circularity. To achieve this, new approaches as integrative mine planning can be introduced to maximize the circular potential of mining operations. This presentation gathers a summary of state-of-the-art initiatives in and around circular economy addressing global examples ranging from energy as an input, consequent use of mining infrastructure and carbon capture initiatives. The selected initiatives are analyzed, and the challenges of their implementation are addressed within the integrative mine planning framework.

2. Materials and Methods

In this research a multi-phase research methodology was followed encompassing an extensive literature review on circular economy, circularity and reported initiatives in the mining industry, followed by a global online survey targeted at diverse stakeholders to obtain current initiatives and applications of circularity in mining. Furthermore, the survey also assessed the participants opinion about how integrated is the circular economy concept in contemporary long-term mine planning. Finally, select case studies were incorporated to illustrate state-of-the-art applications and initiatives of circular economy within the mining sector, providing a holistic view of its implementation and impact.

3. Circularity in mining

The transition to a Circular Economy, as defined by Kirchherr et al., presents an opportunity for the mining sector to evolve towards a more sustainable model. By adopting business models that focus on reducing resource intake and waste, reusing materials whenever possible, recycling resources, and recovering materials throughout the production, distribution, and consumption processes, mining can help to drive sustainable development. This approach not only addresses environmental concerns but also aims to enhance economic prosperity and social equity, benefiting both current and future generations. Embracing circularity in mining is therefore a key step towards achieving environmental quality and aligning the industry with the broader objectives of sustainable development (Kirchherr et al., 2017). Circular economy and circularity are complementary concepts that share the goal of sustainability but operate at different scopes and application levels. In contrast, circularity is specifically focused on the operational aspects of economic, technical, and environmental systems and the integration at an operational level of the 10 Rs of the circular economy: the circular economy in action perse, which addresses recovery, recycle, repurpose, remanufacture, refurbish, repair, reuse, reduce, rethink and refuse along the entire mine lifecycle, minimizing the inputs, reducing waste creation, and maximizing waste reuse and the optimization of all processes involved in the mining projects' life. Both terms are often referred to as synonyms, whereas circularity has a process-oriented approach rather than economy factors. In practical terms, applying the 10 Rs in mining have led to innovations such as employing more efficient extraction techniques that create less waste and emissions, using waste rock in construction or repurposing mine tailings, developing reclamation techniques that ensure the land can return to a natural or useful state including post-mining secondary economic application of mining infrastructure, or utilizing mining by-products in new industries. An overview on contemporary initiatives of circular economy in mining is offered in Table 1.

Table 1: Circular economy initiatives according to the 10 Rs (modified after Potting et al. 2017, Skärin et al. 2022, Nowosad et al. 2023 and Barrak et al. 2024)

	Circularity Categories	Concepts	Circularity Initiative examples
Circular economy	R0 - Refuse R1 - Rethink	Refuse harmful materials, nonrecyclable materials as inputs and refuse of non-renewable sources of energy	Mining operations as Olympic Dam of BHP in Australia, have opted to source electricity from renewable sources going off-grid. This has resulted in lower costs, independence from the electrical network, elimination of blackout risk for remote operations and drastic emission reductions. Off-grid mines powered by renewable sources can drive down energy costs by up to 25% in existing operations, and 50% in the case of new mines (Deloitte, 2017).
		Develop and adapt circular economy models to mining, circular innovation, rethinking mine planning and design from exploration to closure and post-mining, focusing on reducing the environmental footprint and creating circular processes	Alternatives to develop novel approaches such as Modular Mining Systems for scalable and adaptable mining projects, an initiative of Think and Act DifferentTM (TAD) initiative of Oz Minerals, Unearthed and Inspire Resources (TAD, 2022). This concept is based on modular architecture for designing modern mines setting aside traditional mine development and centers on a future full electric, zero-entry, low-emissions, scalable and adaptable mine.
	R2 - Reduce	Overall reduction in the input of resources across the mine lifecycle: energy, waste, and fuel usage, as well as the generation of greenhouse emissions, mine footprint	Different strategies can be implemented for reduction ranging from technological changes towards electrification and automation, to optimization of processes based on ventilation on demand (VoD) as principle to reduce energy consumption. According to ABB, VoD can result in possible annual energy savings of up to 50% (Nyqvist & Serrers, 2020)
	R3 - Reuse	Implement systems to reuse materials and resources part of the mining processes from water in mineral processing, carbon sequestration to improve comminution to the	A significant development is an initiative from Rockburst Technologies, an Australian start up, with their patentpending Transcritical CO2 Pulverization (tCO2) technology where carbon dioxide is used for rock breaking

		economical after use of mining infrastructure in post-mining.	in comminution reaching estimated energy saving levels of up to 55% when compared to traditional methods (Dumas, 2023). Moreover, the early integration of carbon capture and emission reduction policies in relation to carbon credits stand therefore as a profitable opportunity for methane extraction in mining operations (Karmis, 2023).
	R4 - Repair	Stablishing service centers for repairing products and increasing service-based businesses within mining	Optimizing with the use and application of new technologies (digital solutions, artificial intelligence, and machine learning), adopting predictive maintenance strategies to maintain and repair mining equipment to extend its lifespan, and increasing availability through its lifecycle.
	R5 - Refurbish	Applying best practices for mine site restoration through the integration of mine closure and post-mining strategies in the mine design process	After-use of mining facilities and infrastructure is to be planned since early stages to support regional development for the closure and post-mining era to enhance a secondary economical use of the mining infrastructure. Initiatives to use and transform former mine sites into technology hubs as the Innopark in the former Sigmundshall Mine in northern Germany. An innovation center created to support start ups and growing companies with engineer services, energy sources, environmental and laboratory services, logistics, facilities management in one place (K+S, n.d.).
	R6 - Remanufacture	By establishing programs specifically for remanufacturing, by designing components to be remanufactures, by establishing buy back services.	An initiative from the original equipment manufacturer (OEM) Epiroc was introducing Battery as a Service (BaaS). Hereby the battery operation service is purchased for the electric vehicle independently from the manufacturing OEM. After reaching the defined lifespan, the old battery is removed from site and replaced with a new pack whereby the old batteries are remanufactured and used for secondary applications and later recycled (Epiroc, 2020).
	R7 - Repurpose	Repurpose residual materials, all kinds of waste materials, mine tailings, infrastructure.	One option is by integrating waste rock in the construction of facilities or as road construction material within and outside the mine site. Hereby, alliances can be established to nearby quarries for processing and screening, then repurposing of waste rock can reduce costs for development drifts and establish a new source of sustainable construction materials (Segui et al., 2023).
	R8 - Recycle R9 - Recover	Recycling input materials, energy from production, heat and wastewater and machines, recycle products and waste	Alternative approaches such as dry stacking as an alternative to mine tailing dams reduces the environmental footprint of mineral waste deposition and stands as a sustainable alternative applied in mines such as Pogo and Greens Creek in Alaska and Quebec (Neuffer & Scott, 2015).
Linear economy		By extracting valuable materials or energy from mining waste like recovering metals from mine tailings.	In the Gelado tailings dam in Brazil, Vale is repurposing iron ore tailings to produce pellet feed to reduce the volume of tailings disposed in piles or dams. Furthermore, it also reduces the carbon emissions of Vale's steelmaking costumers acquiring the produced high-grade pellets (Vale, 2024).

4. Integrative mine planning for circularity

To achieve sustainable mining practices, it's essential to adopt comprehensive integrative mine planning. This approach covers all the traditional stages of mine planning, from the early phases where project parameters are set, including meticulous data collection, clear objectives, comprehensive planning, as well as risk and crisis assessment and management, and continuous monitoring and improvement. It embeds circular economy principles into the blue mining approach, which centers on reducing inputs used and outputs produced across the mining value chain. The focus of integrative planning is on resource and process optimization, which is key to attaining superior sustainability outcomes and boosting overall productivity. Integrative mine planning also offers a clear map of essential mining resources and a controlled overview on the generated outputs. By evaluating each element and process, planners can pinpoint ways to enhance the use of resources in mining. Lacking such thorough planning could lead to poor resource allocation that results in excess waste, diminished efficiency, and a larger carbon footprint. Furthermore, this presentation showcases the need of integrative mine planning in the context of the circular economy.

5. Conclusion

In conclusion, the circular economy encompasses a strategic and comprehensive vision for achieving sustainability on a broad scale, spanning from individual behaviors to global policies. Circularity, on the other hand, focuses on the practical measures and actions at the technical and process level, essential for implementing the broader principles of the circular economy. Together, these concepts interlock to pave the way toward a sustainable future, ensuring that economic activities are conducted within the planet’s ecological boundaries and contribute to social wellbeing. The circular economy concept is frequently associated with the recovery of tailings in the mining industry, where efforts are concentrated on reclaiming valuable minerals from waste streams. However, its application extends far beyond this singular aspect, infusing into the entire value chain of a mining project. From the initial exploration, where precision techniques can minimize environmental disturbance, through to extraction, processing, and even post-closure land use, circular economy principles can revolutionize efficiency and sustainability. By designing operations to reduce resource use, reusing water and materials, recirculating energy, and remanufacturing equipment, the circular economy framework ensures that every stage of a mining project contributes to a holistic, closed-loop system that significantly reduces waste, lowers environmental impact, and promotes sustainable outcomes across the project's lifespan and beyond.

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7. References

Barrak, E., Rodrigues, C., Antunes, C.H., Freire, F., and Dias, L.C. (2024). Applying multicriteria decision analysis to combine life cycle assessment with circularity indicators. Journal of Cleaner Production. 451: 141872.

Deloitte Touche Tohmatsu (2017). Renewables in Mining: Rethink, Reconsider, Replay. Thought leadership series, Vol. 2. Retrieved December 1, 2023 from: https://www2.deloitte.com/content/dam/Deloitte/global/Documents/Energy-and-Resources/gx-renewables-in-mining-final-report-for-web.pdf

Dumas, A. (2023). Unearthing: Rockburst Technologies dramatically reduces comminution energy requirements. Retrieved October 4, 2023, from: https://unearthed.solutions/news/unearthing-rockburst-technologies-dramatically-reduces-comminution-energy-requirements

Epiroc (2020). Epiroc charges forward with batteries as a service. Retrieved April 15, 2024 from: https://www.epiroc.com/en-kw/newsroom/2020/epiroc-charges-forward-with-batteries-as-a-service

Karmis, M. (2023). The business case of reducing emissions. [Keynote address]. 33rd Annual General Meeting of the Society of Mining Professors, September 11-19, Technische Universität Clausthal, Clausthal-Zellerfeld, Germany.

Kirchherr, J., Reike, D. and Hekkert, M.P. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. Resources, Conservation and Recycling. 127: 221-232.

K+S Aktiengesellschaft. (2024). InnoPark Sigmundshall: Leveraging the past for tomorrow's innovations. Retrieved April 29, 2024 from: https://www.kpluss.com/en-us/about-ks/innovation/innopark-sigmundshall/index.html

Neuffer, D. and Scott, C. (2015). Dry Stack Tailings in Cold Regions: Opportunities and Constraints. In Alaska Miners Association Convention. Retrieved from: https://dxi97tvbmhbca.cloudfront.net/upload/user/image/Presentation_AMA2015_DryStacks_20151105_DPN_-_Copy20191128190541988.pdf

Nowosad, S., Bothe-Fiekert, M. and Langefeld, O. (2023). Blue Mining Strategically Integrates Circular Economy. Mining Reporter Glückauf. 159: 581-593.

Nyqvist, J. and Serres, M. (2020). ABB discusses the benefits of ventilation on demand. Canadian Mining Journal. 37-40.

Potting, J., Hekkert, M.P., Worrell, E. and Hanemaaijer, A. (2017). Circular Economy: Measuring Innovation in the Product Chain. Policy Report. PBL Netherlands Environmental Assessment Agency. Retrieved from: https://www.pbl.nl/uploads/default/downloads/pbl-2016-circular-economy-measuring-innovation-in-product-chains-2544.pdf

Segui, P., Safhi, A.E.M., Amrani, M. and Benzaazoua, M. (2023). Mining Wastes as Road Construction Material: A Review. Multidisciplinary Digital Publishing Institute. 13(1): 90.

Skärin, F., Rösiö, C. And Andersen, A. (2022). An Explorative Study of Circularity Practices in Swedish Manufacturing Companies. Multidisciplinary Digital Publishing Institute. 14(12): 7246.

Think & Act Differently. (2022). Scalable & Adaptable Mining: Reimagine mining through modular architecture and flexibility. Whitepaper. Oz Minerals Exploration Ltd. Retrieved May 1, 2024 from: https://www.thinkactdifferently.com/-/media/project/tad/tad-com-en/imagestadwebsite/220720_scalableadaptable_challenge-whitepaper.pdf

Vale (2024) Integrated report 2023. Retrieved from: https://vale.com/documents/d/guest/valerelatointegrado2023-en-120424-final

Agglomerates for Next Generation Lignin-Based Steel Making

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1. Introduction

The Swedish steel industry is actively pursuing the goal of introducing fossil-free steel into the global market. This ongoing transformation towards sustainable steel production is underpinned by circular economy principles, emphasizing the reuse and recycling of available by-products. (Lavers et al., 2022) Notably, lignin, a by-product derived from the pulp and paper industry, holds unexplored potential as a carbon carrier for diverse applications within the steel industry (Marakana et al., 2021).

Prolonging the life of materials not only contributes to a reduction in landfills but also mitigates the depletion of natural resources. This work addresses the efficient management of resources in two of Sweden's most prominent export-oriented industrial sectors: the pulp and paper industry and the steel industry (Lavers et al., 2022). Furthermore, carbon charged into the electric arc furnace (EAF) is a significant contributor to direct GHG (greenhouse gas) emissions in steelmaking. Carbon consumption from charged coal/coke typically ranges from 3-12 kilograms per ton of liquid steel. Biocarbon, in the form of lignin or biochar, is an appealing alternative to fossil carbon, even though comprehensive information comparing its performance to conventional fossil carbon materials under extreme steelmaking conditions is limited (Drobíková et al., 2018).

The primary objectives of this study are to devise strategies for optimizing the recycling of steel residues (pellet fines) using lignin as a binder and probe the reduction of iron oxide-lignin agglomerates. This feasibility study encompasses the design and fabrication of lignin-loaded agglomerates tailored for the next generation of steel production.

2. Materials and Methods

2.1 Briquetting and Testing

Pellet fines, steel residue, was being used as the prime material with proper additions of binder and biocarbon. Pellet fines (about 95% hematite content with 0.03% moisture content) were used for the briquetting in dry form. Dry lignin supplied by SunCarbon AB was used as received. Cylindrical briquettes were manufactured using a hydraulic piston press by loading 20g of material into a mold with a diameter of 2mm at a compaction pressure of 200kN. A hydraulic compression testing machine was used on each briquette to determine Cold Compressive Strength (CCS) and Splitting Tensile Strength (STS). To obtain a reliable strength value, three briquettes were tested for each CCS and STS measurements and the resultant average value was plotted.

2.2 Reduction Analysis

The reduction degree was estimated by weight loss changes in a thermogravimetric test (TGA in an inert atmosphere). Parallelly, one out of the produced pellet fines recipe that developed satisfactory green (strength of the briquette resulted directly after production) and dry strength (strength of the briquette resulted after 2 hours of oven drying at 85ºC) was selected for smelting trials using Tammann furnace. Smelting trials were carried out in alumina crucibles at a heating rate of 10ºC/min until the temperature reached 1000ºC and maintained that temperature for 1 hour to give sufficient time for the briquettes' self-reduction in nitrogen atmosphere (flow rate ~7 liter/min).

Thereafter, the temperature was raised to ~1600ºC to completely melt the briquettes. After the furnace cooled down and the successful collection of the crucibles, slag, and the metal lump/block/piece were separated by breaking the crucible and each was characterized further. Portable XRF and LECO testing were used to determine the elemental composition of collected slags and metal blocks after the smelting tests. The phase composition of the slags was examined by XRD.

3. Results and Discussion

3.1 Briquetting and testing

Table 1 represents the recipes that were produced with pellet fines, as prime material. The addition of 1% hydrated lime to the lignin-containing briquettes proved to develop moderately good green and dry strength for the final briquettes.

Table 1: Developed recipes for pellet fines being the prime material

Recipe	pellet fines	Hydrated lime	Lignin	biocarbon
R1	100.0	0.0	0.0	0.0
R2	89.0	1.0	10.0	0.0
R3	84.0	1.0	10.0	5.0
R4	94.0	1.0	0.0	5.0
R5	85.0	0.0	10.0	5.0
R6	72.4	1.0	10.0	16.6

In addition to green strength and oven dry strength, the air-drying strength of the briquettes after 72 hours was determined to obtain more understanding of how the extent of drying time influences the quality of the final briquettes. As seen from Figures 1 and 2, the recipe R2, with 1% hydrated lime and 10% lignin proved to be the best candidate for further reduction trials. As anticipated, results confirmed that the addition of biocarbon adversely affects the briquette strength. The biocarbontailored R6 briquettes showed strength enough to perform the reduction test.

3.2 Reduction results

From Figure 3 it can be ascertained that a weight loss of 22.7% could be achieved for R2 briquettes. This weight loss corresponds to 63.4% reduction degree of pellet fines agglomerates when compared to the practically achieved reduction degree for the pellet fines recipes reported by Manu et al., 2023, provided the pellet fines used in this work and Manu et al., 2023 are the same. Hence, this study can be used as a basis for comparison of the reduction extent achieved for pellet fines agglomerates produced in this study. For complete iron oxide reduction, a weight loss above 35,5% would be anticipated. Hence, the calculated amount of biocarbon (16.6%), was added and an additional tailored recipe R6 was produced.

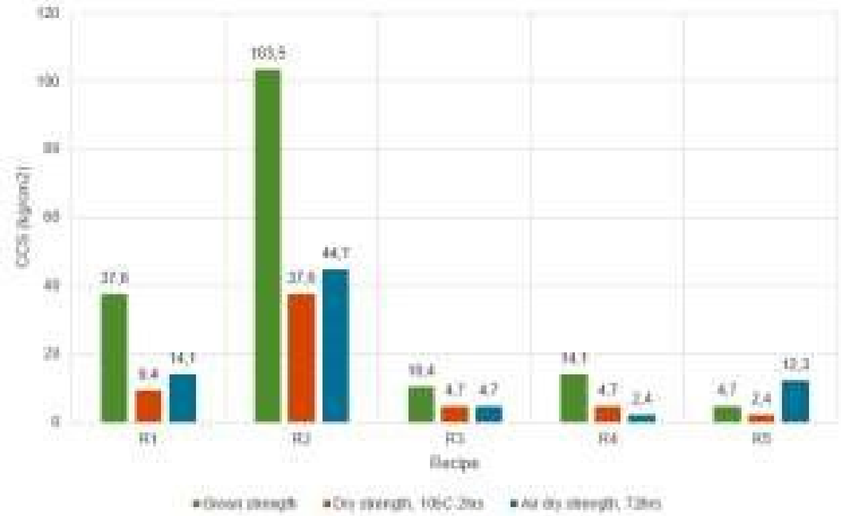

Figure 1: CCS variation for the developed recipes

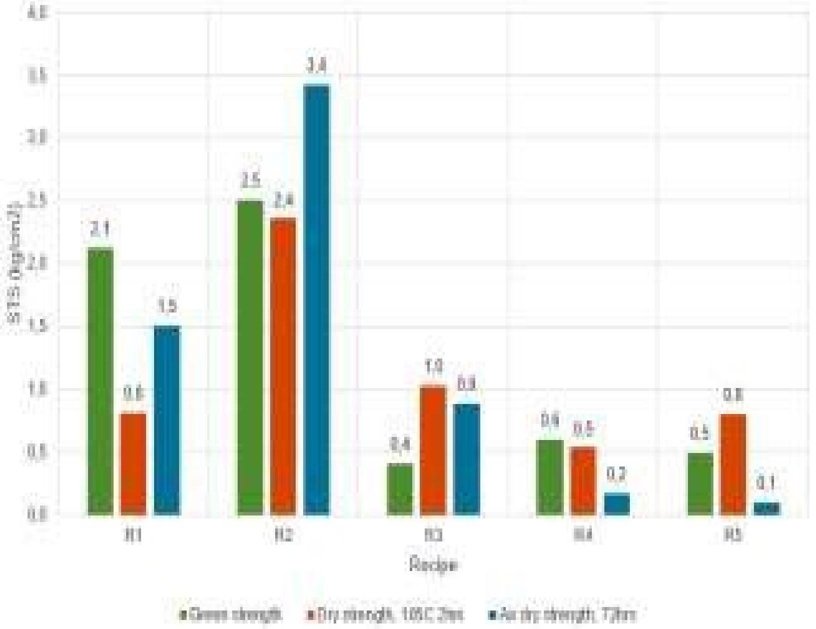

Figure 2: STS variation for the developed recipes

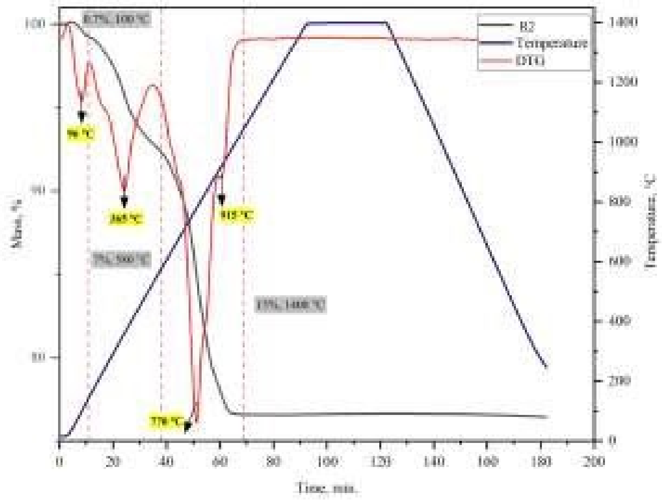

Figure 3: TGA plot for recipe R2

The selected R2 and R6 agglomerates were chosen for Tammann furnace smelting trials. After the smelting test, crucible R6 contained a metal piece, (which was somewhat easier to separate from the crucible) with a small amount of black carbon residue on top, and hence higher carbon content of R6 slag was inferred from LECO analysis. The determined weight loss (40.54%) suggested that a complete reduction of the biocarbon-tailored recipe R6 for the pellet fines was achieved. The elemental composition of isolated slag and metal block are shown in Tables 2 and 3, respectively. The XRD analysis on R2 slag (shown in Figure 4) strongly indicated self-reduction of hematite-type residue. It shall be noted that the occurrence of phase $FeAl_2O_4$ was most likely due to a side reaction of agglomerates with the alumina crucible during melting temperatures and that it may interfere with the theoretical calculations of mass losses based on the expected reduction reaction only.

Table 2: Composition of the slag samples after reduction trials

Recipe	C %	S %	FeO %	Al2O3 %	CaO %	MnO %	SiO2 %	Others, %
R2	0.00	0.06	67.43	7.63	4.06	0.18	4.62	16.02
R6	24.25	0.21	56.01	1.74	7.08	0.16	2.95	7.60

Table 3: Composition of the metal samples after reduction trials

Recipe	C %	S %	Fe %	Al %	Ti %	Cr %	Mn %	Others, %
R2	0.00	0.06	90.18	6.07	0.26	0.01	0.06	3.36
R6	4.40	0.03	88.40	6.00	1.07	0.03	0.07	0.00

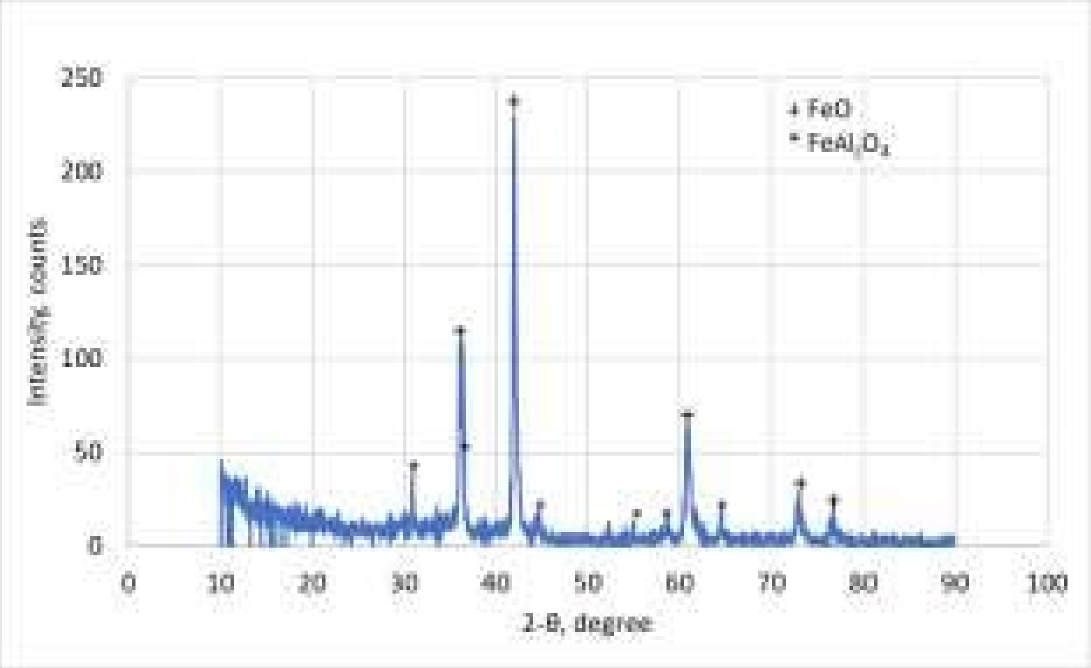

Figure 4: XRD plot for recipe R2 slag

4. Conclusion

The viability of using lignin as a binder and the extent to which lignin can affix the carbon in the melt during reduction has been explored throughout this study. A few of major conclusions inferred from this study are as follows:

- Usage of 1% hydrated lime along with 10% lignin resulted in briquettes with higher strength. Parallelly, the addition of biocarbon has lowered the final briquette strength.
- TGA weight loss approach for estimation of the reduction degree (in R2) put forward the need for the addition of biocarbon. No biocarbon addition trial resulted in 22.7% weight loss corresponding to a maximum 63.4% of self-reduction degree achieved.
- Based on the smelting trials done, the recipe with 10% lignin and 16.6% biocarbon along with 1% hydrated lime was able to achieve a complete reduction with extra biocarbon being resulted in the slag and carbon saturation in the melt.

This initial work marks the ANGELUS project's preliminary stage, with further progress underway.

5. Acknowledgements

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6. References

Drobíková, K., Vallová, S., Motyka, O., Mamulová Kutláková, K., Plachá, D. and Seidlerová, J. (2018). Effects of binder choice in converter and blast furnace sludge briquette preparation: Environmental and practical implications. Waste Management. 79: 30–37.

Lavers, J.L., Bond, A. L. and Rolsky, C. (2022). Far from a distraction: Plastic pollution and the planetary emergency. Biological Conservation. 272: 109655.

Manu, K., Mousa, E., Ahmed, H., Elsadek, M. and Yang, W. (2023) Maximizing the Recycling of Iron Ore Pellets Fines Using Innovative Organic Binders. Materials. 16(10): 3888.

Marakana, P.G., Dey, A. and Saini, B. (2021). Isolation of nanocellulose from lignocellulosic biomass: Synthesis, characterization, modification, and potential applications. Journal of Environmental Chemical Engineering. 9(6): 106606.

An Enviromental-Friendly Process for the Recovery of Tantalum from Waste Capacitors

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Abstract

Tantalum (Ta) is a metallic element naturally occurring within the mineral columbite, which also encompasses niobium. The extraction of pure tantalum from this mineral necessitates highly costly processes such as pyrometallurgy and the utilization of hazardous chemical agents.

Tantalum has been identified as one of the Critical Raw Materials for the European Union in 2023. It possesses a Supply Risk (SR) of 1.3 and a moderate Economic Importance (EI) of 4.8. Its criticality is attributed due to the extraction sites primarily situated in conflict-affected regions. Moreover, the tantalum end-of-life recycling input rate (EOL-RIR) indicates a restricted contribution to the production system from recycling end-of-life scrap, with only 1%. The most common methods for its recovery from e-waste include the use of strong acids, hazardous chemicals, or high-temperature treatment.

Tantalum capacitors are typically a casing of epoxy resin loaded with glass particles, containing three main components: an anode, typically composed of tantalum wire; a cathode, made of manganese oxide or conductive polymer; and a dielectric layer of tantalum pentoxide. Additional conductive layers, such as graphite and silver, are incorporated to minimize resistance to the terminals, often made of Fe-Ni or Cu.

In this work, a process toward a low-cost and sustainable method for the recovery of tantalum from capacitors was performed. The first step was focused on the physical-mechanical treatment. In particular, a batch of capacitors was treated by means of milling, size classification, and magnetic separation, where the terminals, made of Fe-Ni or Cu, were recovered. The electrostatic separation was performed on the non-magnetic fraction, removing the non-conductive product (polymers).

The conductive product, containing mainly Ta, MnO_2, Ag, was next subjected to the chemical treatments, first with ascorbic acid and then with a solution of ammonium thiosulfate, ammonia and copper sulphate, removing MnO_2 and Ag, respectively. Leaching products have been analysed by means of scanning electron microscopy (SEM) and X-ray diffraction (XRD), revealing good results for the application of a green process for tantalum recovery from spent capacitors. The final product, in which 99.9% of Mn and 50% Ag have been removed, consists of a powder with high concentrations of tantalum (up to 94%).

Earth Observation and Technical Approaches

Earth Observation Technologies for a Sustainable Mining Sector: A Social Study

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1. Introduction

Meeting the growing societal demands and achieving the United Nations' Sustainable Development Goals heavily relies on mineral extraction as a fundamental source of raw materials. However, numerous challenges hinder the sector's expansion to meet rising demands. Factors such as ore characteristics and environmental regulations, request innovative solutions throughout the mining supply chain and lifecycle (Steen et al., 2019). The emerging interest in earth observation (EO) technologies, coupled with significant technological advancements, presents opportunities for the mining industry to improve efficiency. Benefits include enhanced time and cost efficiency, adaptability to harsh conditions, and effective data acquisition. Nevertheless, the integration of remote sensing techniques in the extractive industry remains limited, highlighting the need for further systematic practices and advancements in this field.

Despite the essential role of mining in societal progress, there is widespread opposition to extraction activities, particularly regarding new exploration and extraction projects (Ivanović et al., 2023). Well established relations between the community and actors alongside with concern for environmental and social issues, potentially being addressed through innovative solutions consist of the most important aspects for the social responsibility and credibility in mining (Rodrigues et al., 2022). Multiple social studies try to map the opinion of citizens regarding mining, perceived impacts (mostly social and environmental) by assessing the opinion and concerns of the local society, specialists, stakeholders, miners, firm representatives and policy makers (Paat et al., 2021; Seloa & Ngole-Jeme, 2022; Tseer et al., 2024; van der Plank et al., 2016). Another study outlined the differences between the social acceptance of two mining firms in Peru and concluded in the importance of the socio-economic conditions, the engagement and the communication between the firm and society, and additionally the role of the government (Sícoli Pósleman & Sallan, 2019). Musetsho et al. (2021) compared the perceived impacts and influences for land-use/land-cover changes from interviews with EO data evidence.

Although existing literature underlines the expected positive impact of technological integration in the mining industry or the benefits of integrating specifically EO data methods in the industry for topics such as mine rehabilitation (Stothard & Shirani Faradonbeh, 2023), assessing all these in a common framework promoting sustainability hasn't been succeeded yet (Moomen et al., 2019). Earth observation data possess the capability to monitor the multiple impacts of mining across extensive areas and over extended periods of time (Lechner et al., 2019). The integration of new technologies in the extractive industry are able to give new dimension to the sector, by overcoming challenges like safety or environmental protection and upgrading the sector. Though advanced technologies are related to improved impact of the operation the public does not accept easily emerging technologies, partly due to lack of knowledge and familiarity with the respective methods (Lacey et al., 2019). When discussing more in particular EO technologies and their suitability for water quality monitoring, awareness, in recent study Agnoli et al. (2023) identified the direct impacts of the EO data evidence for water quality data, to policy and decision making, by assessing the knowledge, use, trust and problems in measuring and interpreting water quality from EO data. In spite all this, the potential of EO applications in mining and its contribution to social acceptance and engagement is still underexplored.

This work attempts to delineate the potential and constraints associated with the application of Earth Observation (EO) methods throughout the entire life cycle of mining operations. Based on the EU Horizon-funded project S34I (Secure and Sustainable Supply of Raw Materials for EU Industry - https://s34i.eu/) the aim is to define how such technologies contribute to promoting sustainability and identify specific areas of impact. The study incorporates questionnaires and interviews to evaluate the viewpoints and concerns of stakeholders directly impacted by mining operations in Austria, a traditional mining country. Additionally, it assesses the public awareness and interest for the potential utilization of EO tools as a transparent and accessible method for monitoring mining activities. The findings offer valuable insights into the effectiveness of such technological platforms as tools for social engagement and increase the level of social acceptance. Subsequently, they serve as a basis for developing recommendations aimed at effectively leveraging EO technologies from stakeholders such as the mining industry, regulatory authorities, and technological firms. Additionally, the research incorporates case studies that illustrate the practical application and value of EO tools in mining contexts. By bridging the sustainability objectives of the extractive industry with technical expertise, the work contributes to fostering a sustainable future for mining operations.

2. Materials and Methods

In this research the main objectives were identifying the general perception of the Austrian population which live in mining regions were exploitation has been present over centuries and contrast it with populations living in urban centers. Additionally, an important aspect of the research is the integration of EO tools and how this reflects to the opinion and engagement of the citizens, in a further extend connected with the social acceptance of the sector. In this extended abstract, the results of the telephonic questionnaire of locals both from mining and non-mining regions and the interviews from locals and stakeholders from mining regions are presented.

The study followed a mixed method approach of quantitative (firstly) and then qualitative social analysis methods. Namely, in the first phase, 60 quantitative telephonic questionnaires were done in six different mining and urban regions equally distributed. The content of the questionnaire, alongside with some demographic information, was divided in two parts: the first part was based on closedended questions based on a previous poll done in 2016 and supervised by the Austrian Federal Ministry of Science, Research and Economy and the second part was based on closed-ended questions assessing the awareness, trust and acceptability of EO technologies in the context of a mine. In the second phase, semi-structured interviews were performed in two traditional mining regions of Austria (A and B), with stakeholders which are representative for the community (n=8) (i.e. mayors, associations chairmen) which were contacted beforehand and with persons that were found in the streets of the regions and accepted sharing their opinions (n=12). The questions of the semi-structured interviews focused on the same aspects as the initial poll but were adapted to each stakeholder and their role.

The demographic composition remained consistent across the first and second phase. Men constituted the majority, particularly in the interviews, while the age distribution was more balanced in the questionnaires. This was because most interview participants fell within the 40 to 55 age range. Various images of multiple uses of drones and satellites, both in mining and for general use, including an example of interactive monitoring platform, we handed to the participants of the survey for their reference, as supportive material.

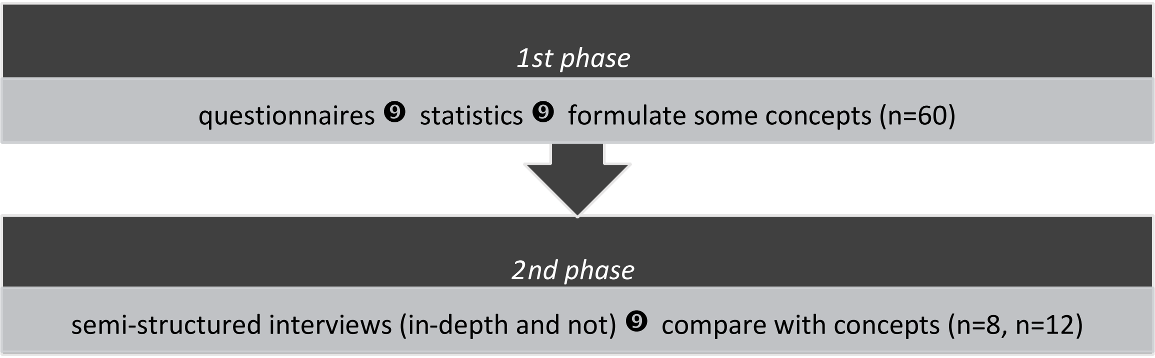

Figure 1. Methodology of the quantitative and qualitative study

3. Results

The following concepts were formulated from the results of the telephonic intereviews:

i. People understand the significance of the extractive sector and its multiple contributions (regional and national), with people from A and B stating bigger importance and acceptance.
ii. Dust, noise and traffic are the most frequently cited disturbing factors in relation to raw material extraction.
iii. The public recognizes the importance of having public participation processes, in mining regions they are more satisfied with these processes rather than non-mining regions, and the legislation overall is adequate for most of the interviewees.
iv. Awareness for raw material extraction of locals close to mining operation is rather good, their opinion for it rather positive and mining operations are well accepted.
v. Respondents do not see them as important beneficiaries from the EO implementation and in an extension their perception and understanding around mining will not change as a result.
vi. In the case of EO data provided, the most trusted provider for the interviewee would be a neutral institution like the university.

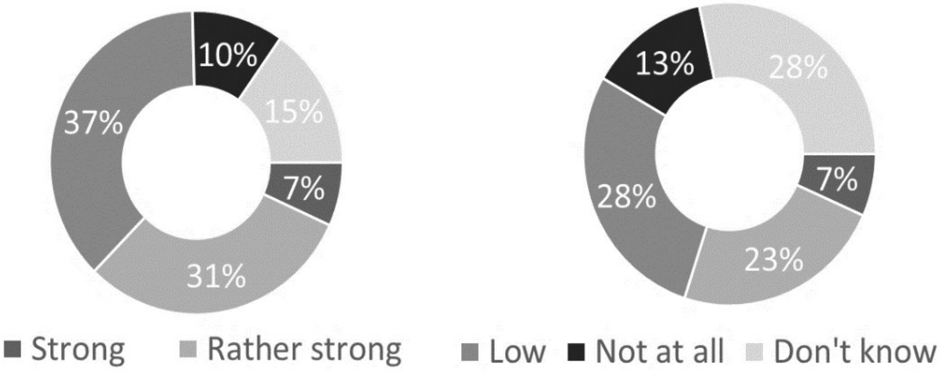

Figure 2. Responses regarding the expected impact in understanding (left) and opinion (right) connected with EO data provided for the mining operation.

Additional observations from the interviews:

- Citizens in A and B localities, although they do not have official engagement events, feel very satisfied with the communication as they have established a direct communication with the operation (related to concept iii.).
- Accidents or fatalities in the mine were mentioned as a known risk and expected events.
- Despite the fact that the locals of the mining regions confirmed the trust and their transparency of the respective mining operations, all unanimously preferred an external neutral institution for providing EO data related to the operation.
- Although it is not directly related to the topic of EO in mining, when drones were mentioned, a lot of comments and the negative impact in data protection were mentioned.
- Almost only half of the interviewees were mentioning that EO data have potential and will contribute positively to the society in the future.
- Environmental impacts were not mentioned at any point of the interviews as something important or disturbing. In general, no major conflicting issues related to mining were reported from the interviewees.
- Only one person at Site B mentioned the inadequate care by the mining company of house damage due to blasting vibrations.
- Almost all of the locals from location A and B, mentioned at least once the local wind orchestras which are known as “Bergkapellen” and/or other touristic attraction events which bring a large quantity of people into the region and to the mining site, therefore raising awareness for the operation and the whole sector.
- Regarding concept ii. and the disturbing factors, people correspond with the factors mentioned.
- No one of the stakeholders that were asked reported any specific impact on their activities originating from the mining operation.
- A case of a company with industrial activity was mentioned, where, due to lack of transparency the society in location B did not support it and, as a result, it failed.
- Overall, transparency and trust to both firms are confessed from the public.
- Almost all of the local’s respondents had direct or indirect professional connections with the operation.

4. Concluding Remarks

4.1 Conclusions

In general, concepts i. through vi. were validated during the interviews, with additional insights and new observations emerging from these discussions. The results from the 2016 survey fully align with the findings from this study. The findings from the research on mapping public opinion indicate that Austrians generally recognize the economic significance of mining, particularly those residing near mining sites who demonstrate more consistent support. Although minor variations in opinions exist between regions with and without mining activity, these differences are not significant. Residents in proximity to mining sites tend to have a more immediate connection to the industry, while those in non-mining regions often lack firsthand experiences and information. Additionally, awareness of EO methods in mining operations appears to be low, and consequently the implementation of these technologies is indifferent for the public, stating that no significant change in the perception for the mine would be experienced, despite their acceptance of the advancements of these technologies. While public participation processes are deemed significant, in regions A and B, such processes are either not established or are compelled by a third party such as the municipality. Nevertheless, the public appears content with the level of communication provided. In both A and B locations, companies have effectively laid the groundwork for collaboration and involvement with the local community. It is noteworthy stating that, in both regions A and B, mining is coexisting with important touristic activities (sometimes even promoting it) and other activities such as hunting, which could be seen as contradictory activities. The survey of stakeholders in various economic activities yielded the same results. No real opinion or request for any change was expressed.

4.2 Future work

The next step of this second phase is to obtain the opinion from similar sample and stakeholders of urban regions. This will aim in comparing the perceptions between people living and being directly affected by the mining operations and revealing the connections and contradictions. Finally, the 3rd phase includes interviews with specialists of the mining and EO sectors area like EO technological companies, mining authorities and governmental representatives, in order to record more in detail, the current gaps, limitations and future possibilities for incorporating EO tools in the Austrian extractive industry.

As a final comment, as it is found in the literature and the current state of industrial use of EO tools in the extractive sectors, there is need for a better integration of the existing EO technology within the industry. In addition, the opportunities and results of such cooperation should be better communicated and disseminated to a wider audience.

5. Acknowledgment

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6. References

Agnoli, L., Urquhart, E., Georgantzis, N., Schaeffer, B., Simmons, R., Hoque, B., Neely, M.B., Neil, C., Oliver, J. and Tyler, A. (2023). Perspectives on user engagement of satellite Earth observation for water quality management. Technological Forecasting and Social Change. 189: 122357.

Institut für Empirische Sozialforschung GMBH. (2016). Rohstoffgewinnung - Gesamtbericht (Issue 01). Retrieved from: https://www.forumrohstoffe.at/wp-content/uploads/2017/12/Rohstoffgewinnung_Gesamtbericht_IFES_2016-05-18.pdf

Ivanović, S., Tomićević-Dubljević, J., Bjedov, I., Đorđević, I. and Živojinović, I. (2023). Cultural landscape management in context: Local communities' perceptions under Jadar mineral extraction project in Serbia. Extractive Industries and Society. 16: 101361.

Lacey, J., Malakar, Y., McCrea, R. and Moffat, K. (2019). Public perceptions of established and emerging mining technologies in Australia. Resources Policy. 62: 125–135.

Lechner, A.M., Owen, J., Ang, M.L.E., Edraki, M., Che Awang, N.A. and Kemp, D. (2019). Historical socio-environmental assessment of resource development footprints using remote sensing. Remote Sensing Applications: Society and Environment. 15: 100236.

Moomen, A.W., Bertolotto, M., Lacroix, P. and Jensen, D. (2019). Inadequate adaptation of geospatial information for sustainable mining towards agenda 2030 sustainable development goals. Journal of Cleaner Production. 238: 117954.

Musetsho, K.D., Chitakira, M. and Nel, W. (2021). Mapping land-use/land-cover change in a critical biodiversity area of south africa. International Journal of Environmental Research and Public Health. 18(19): 10164.

Paat, A., Roosalu, T., Karu, V. and Hitch, M. (2021). Important environmental social governance risks in potential phosphorite mining in Estonia. Extractive Industries and Society. 8(3): 100911.

Rodrigues, M., Alves, M.C., Silva, R. and Oliveira, C. (2022). Mapping the Literature on Social Responsibility and Stakeholders' Pressures in the Mining Industry. In Journal of Risk and Financial Management. 15(10): 425.

Seloa, P. and Ngole-Jeme, V. (2022). Community Perceptions on Environmental and Social Impacts of Mining in Limpopo South Africa and the Implications on Corporate Social Responsibility. Journal of Integrative Environmental Sciences. 19(1), 189–207.

Sícoli Pósleman, C. And Sallan, J.M. (2019). Social license to operate in the mining industry: the case of Peru. Impact Assessment and Project Appraisal. 37(6): 480–490.

Steen, J., Macaulay, S., Kunz, N. and Jackson, J. (2019). Understanding the Innovation Ecosystem in Mining and What the Digital Revolution Means for It. Extracting Innovations. CRC Press.

Stothard, P. and Shirani Faradonbeh, R. (2023). Application of UAVs in the mining industry and towards an integrated UAV-AI-MR technology for mine rehabilitation surveillance. In Mining Technology: Transactions of the Institutions of Mining and Metallurgy. 132(2): 65-88.

Tseer, T., Samuel, M. and Eshun, J.O. (2024). Community security in the context of resource extraction in Koniyaw in the Ashanti region of Ghana. Extractive Industries and Society. 17: 101414.

van der Plank, S., Walsh, B. And Behrens, P. (2016). The expected impacts of mining: Stakeholder perceptions of a proposed mineral sands mine in rural Australia. Resources Policy. 48: 129– 136.

United States Experience in Controlling the Effects of Mining-Induced Seismicity on Surface Structures, Critical for ESG

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1. Introduction

Environmental, Social, and Governance (ESG) considerations are increasingly important in the mining industry, particularly regarding issues related to subsidence and seismicity. Governments and regulatory bodies could impose strict requirements on mining companies to mitigate the environmental and social impacts of subsidence and seismicity. Compliance with these regulations is essential for maintaining a social license to operate eff.

This paper reviews the mechanism of Mining Induced Seismicity (MIS), typical magnitudes, and its effects on essential, and sometimes critical, structures based on MIS monitoring and the United States' experience. It examines new technologies developed for monitoring and analyzing MIS, as well as numerical modeling techniques suitable for predicting seismic events and controlling seismicity through the development of optimized structural mine designs. Additionally, utilizing a case study, it briefly examines the seismic impacts on essential structures and discusses measures taken to control these effects.

Seismicity results from the crushing of rocks and unstable slip along geologic discontinuities that include joints and faults. The released energy is then radiated as seismic waves and detected by a seismograph. Because seismicity resulting from natural (earthquakes) or human related activities, may influence the ground acceleration (strong shaking) near surface structures such as impoundment dams, seismicity is being monitored by national, regional, and local seismic stations in the United States (U.S.). Mining operations are also interested in studying MIS because seismicity may be a trigger mechanism for some coal bumps (Maleki, 2017, 2023) as well as potential effects on surface structures overlying or within proximity of underground coal mines.

In the western U.S., the longwall mining technique has been extensively used for coal extraction, ocassionally in close proximity to essential surface structures such as roads and small impoundment dams. One critical structure, an earthen dam located on the Book Cliffs, Utah, was situated at a short distance (<600-m) from the longwall mining operation. Mining activities were conducted alongside geotechnical investigations and inspections, both during and after completion of mining. These geotechnical investigations were carried out by an independent third party, maintaining ongoing communication with both government entities and the local populace. This paper reviews the effects, addressing geotechnical risk factors and the measures taken by the operator to mitigate risk. These measures included reducing the extraction ratio and improving mine layout designs as mining operations approached the study areas.

2. Materials and Methods

We have completed this study using extensive review of public domain data, collaborations with field geologists, and resource specialists within U.S. government agencies. Typical Mining Induced

Seismicity (MIS) in Colorado and Utah are reviewed, and the progress in new data acquisition, monitoring and analysis techniques that are critical for projecting MIS are reviewed. Finally, we characterize the effects of MIS on critical structures, describe methods of controlling any effects and show how these new techniques will contribute to the protection of natural and man-made resources essential for maintaining a social license.

3. Results and Discussion

3.1 Typical MIS Events

Decades of MIS monitoring in Utah and Colorado indicates moderate level of seismicity for properly engineered modern longwall operations in Colorado and Utah i.e. typically less than 2.5 and often below 3.0 on the Richter scale, Ml (Figure 1). Using the Michigan Tech classifications, these minor events are usually not felt on the surface but can be recorded by seismograph http://www.geo.mtu.edu/UPSeis/magnitude.html. Low magnitude seismic events, however, can trigger coal bumps which can best be controlled through prudent mine layout designs and operating procedures, reducing the potential for high-magnitude “accidental” events (MTI, 2005, Maleki 2023).

The National Institute for Occupational Health and Safety (NIOSH) has long been involved in MIS monitoring in cooperation with the University of Utah (UOU), BLM and other agencies. More recently, NIOSH researchers have implemented an automated system for remotely monitoring MIS within the North Fork Valley (NFV), Colorado. These researchers summarize MIS effects in Utah and Colorado as follows (Swanson et al., 2008). Experience in western U.S. coal mines shows that the largest dynamic failures can produce seismic events with magnitudes in the range of 2-3 with infrequent occurrences up to 4+. Frequently, events with magnitudes up to 2 to 3 occur without any noticeable impact to mining operations or without even an awareness that such an event has occurred. Such events may occur in old workings or in the inaccessible gob areas of current workings where large-scale ground movements attend caving and subsidence.

3.2 Improved Data Collection and Processing

Within the last two decades, improved data collection and processing techniques have been developed by researchers from UOU and NIOSH for the analysis of MIS over the Wasatch Plateau, Utah (WP) and NFV, Colorado. The automated system implemented by NIOSH provides timely event detection and notifications over the NFV, Colorado mining district, complementing University of Utah’s regional system over Utah operations. NIOSH research continues in development of neural networks for improving the quality of automated arrival-time picking as recorded by regional seismic networks (Johnson et al., 2021). These new improvements are critical for confirming expected MIS on existing operations, alerting the operator of MIS pattern for management of mine safety, and providing comfort to the agencies and general public that MIS is understood and potential risk can be monitored.

New data processing techniques being advanced by UOU researchers are promising making it possible for using existing regional seismic systems with accuracy expected from in-mine microseismic systems. These techniques have been applied for back analyses of MIS at the Trail Mountain Mine and more recently at the Crandall Canyon accident site and NFV, Colorado (Pankow et al., 2008, Kubachi et al., 2014, and Chambers et al, 2015) as well as for discriminating natural earthquakes from MIS events (Stein, 2015). These developments could significantly reduce the cost of MIS monitoring, increasing their usage by cost conscious mining companies, and for increasing public confidence.

Another monitoring strategy being advanced by NIOSH is balancing data quality and costeffectiveness effectively by using nodal geophones for temporary surface monitoring. Nodal geophones are a complete seismic station (geophone, battery, digitizer, GPS, etc.) packaged into a rugged container about the size of a coffee can (Chambers, 2020).

3.3 Prediction of MIS

A proper understanding of complex behavior of rock mass under dynamic loading for prediction of MIS has been challenging. New, innovative application of numerical modeling is noted as related to estimating MIS for longwall mining in the western U.S. These studies demonstrate the potential of numerical modeling for analysis/prediction of MIS as a function of mine layout designs for site specific geologic conditions (Maleki et al., 2003, MTI, 2005, Pariseau, 2012). Thus, they are important for controlling MIS through deveolpment of optimum mine layout designs including mine orientaion, longwall panel width, and the need to leave barrier pillars within panels at stratigic locations or between panels (MTI, 2005, Maleki et al. 2020).

3.4 MIS impacts on Critical Structures

The only critical structure which was longwalled at very close spacing (<600-m) is a study dam (GTD) located on the Book Cliffs, Utah. Mining was conducted in conjunction with geotechnical investigations/inspections both during and after completion of mining (2004-2017). The effects are described by RB&G Engineering (2006-2021) after the completion of side-by-side longwall mining in Panel 7 to the southwest of the GTD under cover approaching 800-m.

"It is apparent from the data collected that mining activities at the West Ridge Mine have caused mining-induced seismic events, and the ground motions caused by these events are detectable at GTD and Reservoir. These ground motions have caused some measurable permanent deformations of the ground surface on the hillside west of the reservoir, as well as lateral deformations at the west end of the dam. Despite the recorded deformations, the dam appears to be performing well, and ongoing deformations have been very small since mining of Panel 7 concluded in the fall of 2006".

The study mine operator developed more conservative mine layout designs for extracting Panels 1821 to the northwest of the GTD. The minimum longwall extraction distance to the dam was increased (>1,140-m) while reducing extraction ratio by leaving barrier pillars between panels (panel-barrier designs). These panels were extracted in 2012-2015 in conjunction with geotechnical monitoring; the final inspection report plus engineering chapter of the GTD permit used in this study are posted on the Utah State web site (RB&G 2021).

"UUSS has detected one small seismic event (0.8 Ml) located at a distance of 1.6 miles northwest of the dam. This small event was not detected by the accelerometer located on the dam. It is not known if it is an MIS or natural earthquake. This is the first event detected since August 2015 event (1.2Ml). Weekly reservoir elevation, seepage and piezometer readings have been reported. Visual site inspections did not indicate any signs of significant landslide movements on the hillsides or at the dam. Since the last inspection, RB&G indicate no significant changes in ground movements and no new MIS events during its 2017 inspection. Ware surveying of the dam is included and shows no significant movement of the dam".

The actual experience gained during the extraction of longwall panels at the study mine is in general agreement with numerical modeling completed earlier for evaluation of optimum longwall designs in another Utah mine (MTI, 2005). This should give the public the confidence that, unlike natural earthquakes, MIS can be predicted and controlled through prudent mine designs.

4. Conclusions

In the 21st century, advances in new technologies for seismic monitoring, data analysis, and projection of mining-induced seismicity (MIS) as a function of mine designs hold promise for improving mine safety management and environmental assessments. These techniques are gradually being improved and field-tested, increasing public confidence in the ability to predict MIS and protect critical structures. Decades of MIS monitoring indicate a moderate level of seismicity for properly engineered modern longwall operations in Colorado and Utah, typically registering less than 2.5 and often below 3.0 on the Richter scale. Using the Michigan Tech classifications, these minor events are usually not felt on the surface and thus have not significantly impacted roads and overlying structures in the western U.S. Critical structures such as impoundment dams can be protected by maintaining sufficient barriers and using prudent mine layout designs and extraction ratios.

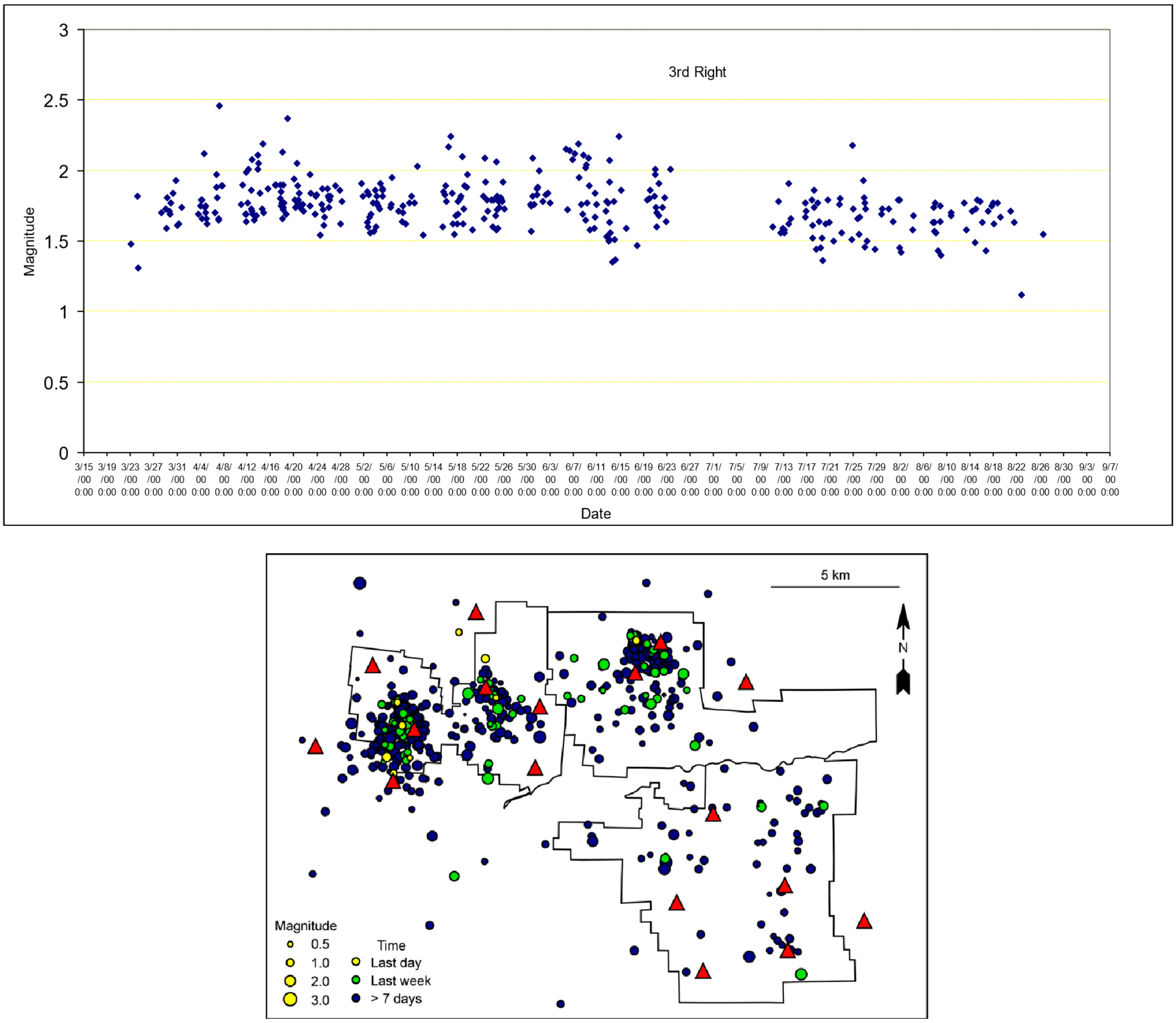

Figure 1. MIS monitoring results during extraction of one longwall panel in Utah (top), after Arabsz et al. (2002) and for a two-month monitoring period in Colorado in the vicinity of two active longwall opearions and other inactive operations (central and northeastern block), after Swanson et al., 2017 (bottom). The distribution of general seismic activity across this district shows that there is a significant variety in the seismic response of both the active and formerly active mining areas.

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6. References

Arabasz, W.J., Ake, J., McCarter, M.K. and McGarr, A. (2002). Mining-Induced seismicity near Joes Valley Dam. Summary of Ground-Motion Studies and Assessment of Probable Maximum Magnitude. Report prepared for State of Utah, School and Institutional Trust Lands Administration, Salt Lake City, Utah. 19 pp.

Chambers, D.J.C., Koper, K.D. and Pankow, K.L. (2015). Detecting and Characterizing Coal Mine Related Seismicity Using Subspace Methods. Geophys. J. Int. 203: 1388-1399.

Johnson, S., Chambers, D., Bolts, M. and Koper, K. (2021). Application of a convolutional neural network for seismic phase picking of mining-induced seismicity. Geophys. J. Int. 224(1): 230-240.

Kubacki, T., Koper, K.D., Pankow, K.L. and McCarter, M.K. (2014). Changes in mining-induced seismicity before and after the 2007 Crandall Canyon Mine collapse. J. Geophys. Res. Solid Earth. 119(6): 4876-4889.

Maleki, H. (2017). Coal pillar mechanics of violent failure in U.S. mines. Int. J. Min. Sci. Technol. 27(3): 387–392.

Maleki, H. (2023). Control of High-order seismicity in deep United States mines through structural mine designs. In the proceedings of the 42nd International Conference on Ground Control.

Maleki, H., Semborski C. and Fleck K. (2012). The importance of Geologic and Geotechnical Investigations for Improving Two-seam Designs. In the proceedings of SME 2012 Annual Meeting, Seattle, WA, (SME Henry Krumb Lecture Series).

Maleki, H., Semborski C. and Fleck, K. (2020). Two Seam Stress Control at the Energy West Mining Operations, Utah, ARMA 20-1319. American Rock Mechanics Association.

MTI (2005). Control of mining-induced seismicity through mine design: Application of U.S. experience and numerical modeling for the Cottonwood Tract. Report prepared by MTI to SITLA. Spokane, WA: Maleki Technologies, Inc.

RB&G (2011). Engineering MIS reports relating to the Grassy Trail Dam, 2006, 2007, 2011. Partial Reports transmitted to Maleki Technologies, Inc. by Jeff McKenzie, BLM.

RB&G (2021). Engineering inspection reports and permitting for 2021.

Stein J. (2015). Discriminating Mining Induced Seismicity from Natural Tectonic Earthquakes in the WP BC Area. PPT presentation, Price, Utah.

Swanson, P., Stewart, C. and Koontz, W. (2008). Monitoring Coal Mine Seismicity with an Automated Wireless Digital Strong-Motion Network, In the proceedings of the 27th International Conference on Ground Control in Mining, 2008.

Small-Scale Mining in Ecuador: Peculiarities and Perspectives

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Keywords: Small-Scale Mining, Artisanal Mining, Sustainability, Drill & Blast

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Abstract

Artisanal and small-scale mining (ASM) is a leading activity in the mining industry: considering only gold, it produces about 20% of the world's market offers. Nevertheless, ASM is generally associated with the negative aspects of its environmental impact, and operational research is generally neglected. This paper shows the techniques adopted for the exploitation of small underground mines in the settlement of Nambija (Ecuador), where there are still rather dated and inefficient activities, often dangerous for the safety of the workers. Today, due to the current price of gold, thousands of artisanal small-scale mines operate without the financial or technical capacity to upgrade their production techniques, often using equipment and working methods that were forsaken decades ago in the conventional mining industry. This is also the case with Nambija. After a series of fluctuations characterized by a sort of "gold rush" without any organized and logical exploitation plan but simply based on the extraction of the most easily accessible volumes, two new cooperatives based in Zamora have recently started a research campaign aimed at improving conditions and achieving more conscious exploitation. Approaching a discussion about the sustainable management of small-scale mining unavoidably leads to dealing with the abstractness of the concept of “sustainability” and the vagueness of the definition of “small scale” in mining (Hentschel et al., 2002). Hence, there is a need to begin with a few definitions. Sustainability is a concept with many definitions and mainly depends on the reality being considered and the scale factor of this reality. The mainstream thinking of sustainability scholars visualizes three dimensions: environmental, social, and economic sustainability (Almeida and Torrens, 2002). The paper deepens these aspects to rationalize the operations that could be carried out to value the activity of the ASM.

References

Almeida, D.A. and Torrens. R.B. (2022). Criterios generales de sostenibilidad para la actividad minera. Indicadores de Sostenibilidad para la Industria Extractiva Mineral, Roberto C. Villas-Bôas, Chirstian Beinhoff (Eds.). pp. 93 -116.

Hentschel, T., Hruschka, F. and Priester. M. (2002). Global Report on Artisanal & Small-Scale Mining. International Institute for Environment and Development. Retrieved from: http://pubs.iied.org/pdfs/G00723.pdf

Acceptable Risk Evaluation of Dewatering Opencast Mines with Extreme Precipitation

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Abstract

In the conditions of existing climate change with increased extreme peak precipitations, opencast mines are threatened with significantly increased ecological risks due to surface dewatering system failure. Increasing frequency of heavy rainfall and possible floods, landslides, and erosions with mud occurrences with a large accompanying cost of remediation and environmental protection of the consequences. Company acceptable risk expressed in monetary units is determined by harmonizing dewatering additional construction costs for more reliable operation with the real possible risk obtained by multiplying total remediation costs by the acceptable failure probability. Acceptable risk evaluation for opencast mine variable boundaries in time requires periodic iterative optimisation of all operational parameters for sizing surface dewatering objects for protection from extreme precipitation and possible floods with an appropriate return period. Based on the established risk evaluation model, an analysis of the reliability of the flood dewatering system was done using the example of the opencast coal mine Drmno.

References

Pavlovic, N., Subaranovic T. and Ignjatovic. D. (2022). Impact of Extreme Natural Processes on Opencast Mining Risks. In the proceedings of the 15th International Conference OMC 2022. pp. 143-146.

Pavlovic, D., Ignjatovic, N., Djenadic, S., Subaranovic, T. and Jakovljevic, I. (2020). Assessment of social and environmental risks on opencast coal mines. International Journal of Mining and Mineral Engineering. 10(2/3/4): 271-287.

Critical Minerals

Never Let a Good Crisis Go to Waste: Greenwashing and the Fallacy of Critical Minerals

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Abstract

As decarbonisation goes mainstream, mining companies are hopping on the bandwagon and increasingly branding their products as critical for the clean energy economy. While demand for these so-called "critical minerals" is projected to increase, serious questions remain about the need for new raw materials and mining's role in the clean energy transition. Despite the unknowns, it is clear that we cannot simply mine our way out of the complex and multi-faceted problem of climate change.

It is called greenwashing when companies exaggerate their environmental commitments to appeal to consumers' concerns for the Earth. Greenwashing is a well-documented marketing tool used by virtually all industries where there's money to be made from eco-conscious consumers, from fossil fuels to fast fashion, with incarnations ranging from sophisticated to ridiculous.

The deceptive tactic is aimed at convincing the public that a company's products or services are "eco-friendly" by advertising superficial improvements and making shallow promises that require little to no substantive change in how the company does business. For example, catchy slogans and public commitments to ramp up renewable energy can give the impression that giant oil and gas companies take climate change seriously, even as they open new oil and gas fields.

The mining industry is among many trying to capitalise on the worsening climate crisis. It's using greenwashing tactics to grease the wheels on controversial proposals by branding itself as a climate leader. Mining companies use greenwashing tactics like distracting one-off sustainability initiatives and "green" marketing to avoid the difficult and expensive task of meaningfully integrating environmental and social responsibility throughout operations.

The most ubiquitous talking point is that we must mine for the metals we need to transition to a clean energy economy. Here is why it does not hold water: new mining is often at direct odds with our actions to address climate change. For example, sulphide mining proposals would include biological features such as sensitive wetlands, even though protecting wetlands is one approach in our toolbox's most effective climate strategy. Arguments suggesting, we must choose mining for clean energy metals at their expense are disingenuous, dangerous, and divisive.

And the metals we need for the clean energy transition are already above ground. Still, they're being sent to landfills and other countries for recycling because of insufficient metal recycling infrastructure in North America and Europe. The so-called need for new metals drops if we bolster domestic recycling efforts. Additionally, justifications for new mining based on future demand don't account for the steps we could take today to reduce reliance on mined materials, including passing long

overdue comprehensive metal recovery policies and investing in less resource-intensive clean energy solutions.

Lastly, there must be evidence that mining companies intend to use newly mined metals for renewable energy. No company proposing a mine in Canada has a legally binding contract to sell its products to a domestic clean energy supplier. When pressed, mining companies will admit that they would likely ship ore concentrates out of North, Europe, and Australia to be smelted and refined elsewhere.

Setting all else aside, the industry business model to date has been to tell the public what they want to hear to push the proposal through the permitting process, then once up and running, keep costs as low as possible and sell to the highest bidder. Until backed up with hard evidence and binding commitments, industry claims about mining's role as a responsible climate leader can be rightfully regarded as greenwashing.

Assessment of Critical and Strategic Raw Materials for Australia using an AHP-Based Smart Computational Tool

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1. Introduction

Due to various factors in different periods of the past two centuries, namely advancing technology, population growth, and even nowadays, the net zero emission goals, the supply and demand of minerals and metals have raised concerns. These concerns pushed many governments to take steps to assess the criticality of such commodities.

Determining critical and strategic raw materials and their impact factors is essential to ensuring an efficient and sustainable supply within the mining industry globally. Criticality is generally defined as a combination of a commodity's economic importance and the risk of supply disruption (Buijs et al., 2012; Schrijvers et al., 2020). It is an undeniable fact that raw materials are the backbone of many commercial and industrial sectors globally. No matter the era, their economic importance was one of the primary reasons that had an outstanding impact on their criticality status. Nevertheless, it is impossible to assess and decide according to only one impact factor; criticality is not a singular aspect but rather a complex interplay of economic, environmental, geopolitical, social, and cultural factors (Castro-Sejin et al., 2023).

The term 'criticality' has evolved over time. During World Wars I and II, strategic raw materials were deemed critical due to their unavailability during war or national emergencies (U.S. Congress, 1939; Roush, 1939). In the 1950s, as the modern economy grew more complex, challenges related to materials, defence, emergencies, limited supply, and urbanization reshaped the concept of criticality. Since then, 'critical' has been used for emergency situations, while 'strategic raw materials' are reserved for strategic purposes and available cases. This historical context is crucial for understanding the current discourse on criticality (Orchard, 1951).

This research holds significant implications for Australia's strategic planning. By identifying and evaluating critical and strategic minerals in a more comprehensive manner, Australia can formulate a more detailed plan to exploit these commodities more efficiently, thereby positioning itself as a key player in global commodities markets.

2. Literature Review

Several countries and unions have initiated discussions on critical raw materials (CRMs); some have published official CRM lists. However, only eight have developed or implemented transparent criticality assessment methodologies. Among these are traditional and emerging mining-producing nations like China, India, and the US, as well as critical minerals consumers in Europe and Japan (Table 1) (Zappettini, 2021; Mammadli et al., 2024). On the contrary, and despite having abundant natural resources and strong mining sectors, Australia and Canada have published critical minerals lists but have not yet conducted official criticality assessments. Most evaluation studies focus on assessing supply risks directly linked to sustainable economic practices. Except for the evaluation conducted in Argentina, supply risk is a primary parameter and forms the foundation for all official criticality assessments, as illustrated in Figure 1.

Table 1 Latest official criticality assessment method according to the countries.

Methodology	Year	Country	Most highlighted criteria	CRM
NAS/DOE	2023	USA	Supply risk, impact of supply restriction	37
EC	2023	EU	Supply risk, economic importance	34
MOTIE	2023	S. Korea	Rarity, unstable supply, unstable price	33
MMGI	2023	India	Supply risk, economic importance	30
BGS	2021	UK	Supply risk, economic vulnerability	18
SegemAR	2021	Argentina	Economic importance, availability	0
METI	2020	Japan	Production/ reserves oligopoly, volatility	35
NPMR	2016	China	Economic importance, competitive advantage	24

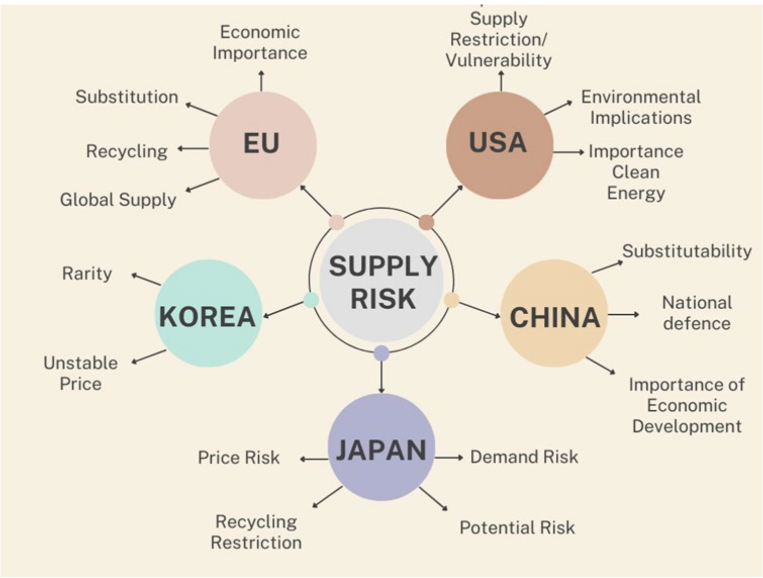

Figure.1. Supply Risk as the Foundation of Official Criticality Assessments globally.

Figure 1 also illustrates other parameters that are essential in identifying critical raw materials. Nonetheless, criticality is a complex and multifaceted concept, and the factors behind it should not be as simple; criticality encompasses a wide range of factors that must be considered. These include deposits' characteristics, like their concentration, processing facilities in a particular location, market factors, demand for high-tech sectors, social considerations, regulatory structures, geopolitical factors, environmental concerns, recycling potential, substitutability, and sustainability, among others (Graedel &Reck, 2016).

Assessing the criticality of minerals and metals has become increasingly paramount worldwide. The United States of America has conducted ten official criticality assessments by various government organizations from 1939 to 2023 (USDOE, 2023). The European Union's (EU) criticality assessments have gained global recognition (EC, 2023) to the extent that other countries, like India, have adopted and modified the EU methodology to suit their needs. India's approach, which focuses on recognizing and managing its resource dependencies by modification of EU assessment, stands out, while Argentina's 2021 assessment sets a precedent for South America. Japan and South Korea, both significant players in manufacturing, have conducted their assessments, as China is a global leader in several critical commodities. On the other hand, Africa lacks evidence of either official criticality evaluations or published lists. As mentioned, Australia and Canada have only published lists of their critical minerals, demonstrating their strategic resource considerations, with Canada's last known list published in 2022 and Australia's in 2024 (Natural Resources Canada, 2022; Hughes et al., 2024).

2.1 Australia's Resource Strategy and Policies

Australia is a global mining powerhouse, ranking among the top producers of bauxite, coal, cobalt, copper, gold, ilmenite, iron, lead, lithium, magnesite, manganese ore, molybdenum, nickel, rutile, silver, tin, tungsten, uranium, vanadium, zirconium, and zinc (Barakos et al., 2022; Hughes et al., 2024). A detailed classification of commodities produced in Australia based on their production, reserves, concentration, significance, and criticality is illustrated in Table 2 below.

Table 2. Resources in Australia classified into categories.

In Production	Aluminium, Antimony, Baryte, Bentonite, Cadmium, Cobalt, Coking Coal, Copper, Diatomite, Feldspar, Gold, Gypsum, Helium, Iron, Lead, Lithium, Magnesium, Manganese, Molybdenum, Nickel, PGM, Phosphate, Potash, REE, Salt, Silver, Talc, Tantalum, Tin, Titanium, Tungsten, Uranium, Zinc, Zirconium
Vast Resources	Aluminium, Antimony, Bentonite, Cobalt, Coal, Copper, Gold, Gypsum, Iron, Lead, Lithium, Magnesium, Manganese, Molybdenum, N. Graphite, Nickel, Niobium, REE, Salt, Scandium, Silver, Tin, Titanium, Uranium, Vanadium, Zinc, Zirconium
Small Resources	Baryte, Fluorine, N. Graphite, Scandium, Tantalum
Minor concentrations	Arsenic
Not Critical	Bentonite, Diatomite, Gypsum, Potash, Salt, Talc

For the first time in 2013, the Australian government published a report on 33 critical minerals, demonstrating the country's potential to meet global demand (Skirrow et al., 2013). After that, Australia published its first official critical mineral list in 2019 with 24, 2022 with 26, and the most recent list published in 2024 with 31 critical commodities (Austrade, 2019; Department of Industry, Science, Energy and Resources, 2022; Hughes et al., 2024). It is important to note that despite publishing all these lists regarding the criticality of minerals, Geoscience Australia, or any other agency never released the evaluation process details.

3. Methodology

Combining the data from Geoscience Australia and other official critical mineral lists worldwide, we selected 32 of the 40 commodities to be assessed for their criticality and strategic importance (Table 3). Two of the options are apparent (critical, not critical). A third option (strategic) was included because some commodities may not meet the criticality criteria outlined in the literature review but are still essential for Australia's economic development or geo-political reasons.

Table 3. List of commodities to be examined for their criticality in Australia

Commodities to be assessed	Aluminium, Antimony, Arsenic, Baryte, Cobalt, Coking Coal, Copper, Feldspar, Fluorine, Gold, Iron, Lead, Lithium, Magnesium, Manganese, Molybdenum, Graphite, Nickel, Niobium, PGM, Phosphate, REE, Scandium, Silver

Further on, various criteria are used with the evaluation, employing a multi-criteria decision analysis (MCDA) process and the Analytical Hierarchical Process (AHP) to evaluate all the parameters simultaneously. For this study, 25 impact variables affecting raw materials' criticality were identified and divided into five categories (Figure 2). A small group of experts was brought together to make the evaluations based on all the available data and information. The selected AHP methodology facilitates a more rigorous and transparent decision-making process by giving decision-makers a systematic and organised manner to convey their judgements. This makes it possible to comprehend the stability and dependability of the decision-making outcomes better (Mammadli et al., 2022;2024). A sophisticated algorithm in the form of a computational tool was used to ease the calculations (Saaty, 1980; Ishizaka & Nemery, 2013).

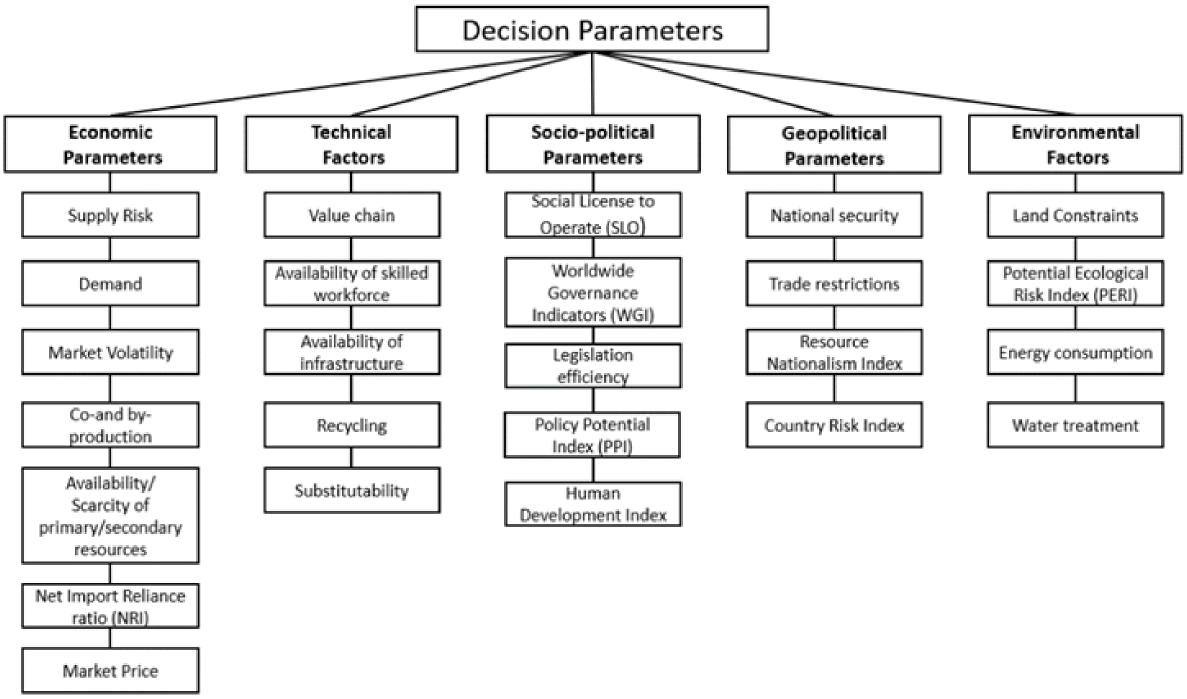

Fig. 2. Classification of the decision parameters for the criticality assessment of raw materials

4. Criticality evaluation results and discussion

The experts conducted the evaluation, considering various parameters and based on the information and data provided for each of the 32 commodities. Weight factors were determined for all parameters for each commodity under evaluation. Table 4 displays the top three criteria for each metal's evaluation process, which signify the most impactful factors for each commodity. Criteria like the value chain, supply risk, demand, water treatment, and national security were among the most essential for many minerals.

The demand for copper, for instance, is expected to play a significant role in its future global characterisation as critical. In some jurisdictions around the world including Canada and the state of South Australia copper has already been characterised as critical. In this study it is still considered more as a strategic commodity, although the tendency to be regarded as critical is growing.

Additionally, the percentages of the three options for each commodity show the tendency to characterise them as critical, strategic, or not critical. All examined 32 minerals in this work were identified as critical or strategic. Rare earth elements (REE), platinum group metals (PGM), and niobium have the highest percentages in criticality. Australia ranks high in the mining production of rare earths; however, the challenges in domestic downstream processing impact the security of their supply chain. The supply risk for PGM and Scandium is crucial in determining their criticality. Other metals like gold, silver, baryte, coking coal, iron and tin are deemed primarily strategic due to their high values, high production, and abundance in Australia. It should also be highlighted that commodities like uranium, gold, vanadium, zirconium, tungsten, and titanium raise national security concerns.

Table 4: Evaluated elements.

CRM	Critical	Strategic	Not Critical	Top 3 criteria
Aluminium	43%	**44%**	12%	Demand (12%), Value Chain (8%), Energy Consumption (8%)
Antimony	**56%**	34%	10%	Demand (14%), PERI (10%), Market Volatility & National Security (9%),
Arsenic	**54%**	34%	12%	National Security (9%), PERI (21%), Water Treatment (8%)
Baryte	36%	**53%**	11%	Demand (9%), Market Volatility (8%), Water Treatment (11%)
Cobalt	44%	**48%**	8%	Demand (14%), Market Volatility (9%), Energy Consumption (10%)
Coking Coal	36%	**51%**	13%	Demand (18%), Substitutability (9%), Market price (8%)
Copper	38%	**51%**	11%	Demand (17%), Co-and-by-production & Availability (7%), Market price (10%)
Feldspar	39%	**50%**	11%	Demand (17%), Market Volatility (9%), Substitutability & Water Treatment (7%)
Fluorine	56%	34%	10%	Supply risk (11 %), National Security & PERI (9%)
Gold	46%	**48%**	6%	Demand (16%), Market Price (13%), National Security (9%)
Iron	30%	**46%**	23%	Demand & Value Chain (11%), Recycling (10%)
Lead	42%	**45%**	13%	Demand (17%), Co-and-by-production (7%), PERI (11%)
Lithium	45%	**47%**	8%	Demand (24%), Market price (9%), Trade restriction/embargos & Water Treatment (7%)
Magnesium	42%	**48%**	10%	Demand (17%), Co-and-by-production (6%), Market price (6%)
Manganese	44%	**47%**	9%	Demand (14%), Market price (8%), SLO (7%)
Molybdenum	39%	**48%**	13%	Demand (13%), Co-and-by-production (10%), Value Chain (8%)
N. Graphite	**56%**	35%	9%	Supply Risk & Demand (10%), Value Chain (9%)
Nickel	**56%**	36%	8%	Demand & Trade restriction/embargos (14%), Market Volatility (7%),
Niobium	**59%**	31%	10%	Supply Risk (10 %), Demand (11%), National Security (9%)
PGM	**60%**	33%	7%	Supply Risk & Demand (11%), Trade restriction/embargos (9%)
Phosphate	37%	**49%**	13%	Demand (21%), Market price & SLO (7%)
REE	**64%**	29%	7%	Demand (14%), Value Chain (12%), Trade restriction/embargos (8%)
Scandium	**55%**	35%	10%	Supply Risk (13 %), Value Chain & Trade restriction/embargos (8%)
Silver	36%	**57%**	6%	Demand (16%), Co-and-by-production (10%), National Security (9%)
Tantalum	**57%**	33%	10%	Demand (16%), Value Chain & National Security (8%)
Tin	37%	**50%**	13%	Demand (17%), Co-and-by-production (8%), Value Chain (10%)
Titanium	46%	**47%**	7%	Demand (20%), National Security (11), Trade restriction/embargos (9 %)
Tungsten	**57%**	34%	9%	Supply risk (11 %), National Security, & Trade restriction/embargos (10 %)
Uranium	**53%**	39%	8%	Demand & National Security (13%), PERI (11%)
Vanadium	**56%**	35%	9%	Demand (14%), National Security (9%), Net Import Reliance & Value Chain (8%)
Zinc	34%	**54%**	12%	Demand (14%), Value Chain & Recycling (9%)
Zirconium	**48%**	44%	8%	Demand (14%), National Security (12%), Co-and-by-production (9%)

Australia also has notable production of battery raw materials. Lithium is considered strategic because of Australia's dominance in global production and its significance in the batteries industry, among other applications. Regarding cobalt and manganese, Australia ranks excessively in extraction and processing, which is essential for the industry. Furthermore, the extensive domestic manufacturing and the latest geopolitical problems spotlight the criticality of nickel. On the other hand, the supply risk and demand for natural graphite in Australia make it vital for the local economy.

It is crucial to acknowledge that in 2024, the Australian government updated its critical raw materials list and introduced new materials. However, these minerals remain uncertain due to the lack of information on their reserves, production, and processing within the country. Without comprehensive data on these minerals, namely "beryllium, bismuth, chromium, gallium, germanium, hafnium, helium, indium," we were unable to include them in the list of examined minerals.

5. Conclusions

In the last decade, official and non-official criticality studies have been conducted regarding Australian resources. However, neither governmental nor academic criticality assessment has been undertaken in depth. This work is the first detailed assessment discussing all the parameters that impact the criticality of Australian commodities. Due to time and resources, the authors applied filters and focused on minerals and metals essential to Australia.

This methodology enabled the assessment of 32 commodities under numerous impact factors and helped us understand the characteristics, degree of impact, and essentiality of each parameter for each commodity independently. Using quantitative approaches, the authors also classified commodities as critical, strategic, and non-critical. Interestingly, some minerals, such as cobalt, lead, lithium, tin, and titanium, have been considered critical in many countries. In contrast, these minerals were assessed in this work for Australia, and the outcomes demonstrated that they are rather strategic.

Implementing this methodology will benefit the Australian mining sector, leading to more resilient and sustainable mining on a global scale. It will also guide policymakers, decision-makers, researchers, and investors in making informed decisions.

The limitations of this study are attributed to the availability of data and resources to apply the developed tool for the criticality assessment of more commodities with more data and utilising the knowledge of more experts. This could help create an expanded critical raw materials list for Australia, which would contribute to shaping an optimized strategic plan for exploiting the nation’s natural resources.

6. References

Barakos, G., Dyer, L., and Hitch, M. (2022). The long uphill journey of Australia’s rare earth element industry: Challenges and opportunities. International Journal of Mining, Reclamation and Environment. 36(9): 1–20.

Buijs, B., Sievers, H., and Espinoza, L.A.T. (2012). Limits to the critical raw materials approach. In the proceedings of the Institution of Civil Engineers - Waste and Resource Management. 165(4): 201-208.

Castro-Sejin, A., Mammadli, A., and Barakos, G. (2023). Criticality of raw materials–a clarification and redefinition of the term worldwide. In the proceedings of the Critical Minerals Conference 2023. AusIMM.

Department of Industry, Innovation and Science. (2019). Australia’s Critical Minerals Strategy. Australian Trade and Investment Commission.

Department of Industry, Science and Resources. (2022). Critical minerals strategy, Australian Government.

European Commission. (2023). Study on the critical raw materials for the EU 2023.

Graedel, T.E. and Reck, B.K. (2016). Six Years of Criticality Assessments: What Have We Learned So Far? Journal of Industrial Ecology. 20(4): 692-699.

Hughes, A., Britt, A., Pheeney, J., Morfiadakis, A., Kucka, C., Colclough, H., Munns, C., Senior, A., Cross, A., Summerfield, D., Hitchman, A., Cheng, Y., Walsh, J., Thorne, J. and Sexton, M. (2024). Australia's Identified Mineral Resources 2023. Canberra.

Ishizaka, A. and Nemery, P. (2013). Multi-criteria decision analysis: methods and software. John Wiley & Sons.

Mammadli, A., Barakos, G., Islam, M.A., Mischo, H. and Hitch, M. (2022). Development of a Smart Computational Tool for the Evaluation of Co- and By-Products in Mining Projects Using Chovdar Gold Ore Deposit in Azerbaijan as a Case Study. Mining. 2(3): 487-510.

Mammadli, A., Barakos, G., Chang, P. Gamutan, J., Efendiyeva, Z. (2023). Evaluation of potentially critical and strategic raw materials in Azerbaijan In: Shukurov, A., Vovk, O., Zaporozhets, A., Zuievska, N. (eds) Geomining. Studies in Systems, Decision and Control. Springer, Cham. 224: 3-29.

Natural Resources Canada. (2022). The Canadian Critical Minerals Strategy. Retrieved from: https://www.canada.ca/content/dam/nrcan-rncan/site/critical-minerals/Critical-minerals-strategyDec09.pdf

Orchard, J.E. (1951). Strategic Materials: Procurement and Allocation. Proceedings of the Academy of Political Science. 24(3): 19-40.

Roush, G.A. (1939). Strategic mineral supplies. McGraw-Hill Book Company

Saaty, T.L. (1980). The analytic hierarchy process (AHP). The Journal of the Operational Research Society. 41(11): 1073-1076.

Schrijvers, D., Hool, A., Blengini, G.A., Chen, W.Q., Dewulf, J., Eggert, R., van Ellen, L., Gauss, R., Goddin, J., Habib, K., Hagelüken, C., Hirohata, A., Hofmann-Amtenbrink, M., Kosmol, J., Le Gleuher, M., Grohol, M., Ku, A., Lee, M.H., Liu, G., Nansai, K., Nuss, P., Peck, D., Reller, A., Sonnemann, G., Tercero, L., Thorenz, A. and Wäger, P.A. (2020). A review of methods and data to determine raw material criticality. Resources, Conservation and Recycling, 155: 104617.

Skirrow, R.G., Huston, D.L., Mernagh, T.P., Throne, J.P., Dulfer, H. and Senior, A.B. (2013). Critical commodities for a high-tech world: Australia's potential to supply global demand. 126. Geoscience Australia.

US Congress (1939). Strategic and Critical Materials Stock Piling Act.

US Department of Energy (2023). Critical Materials Assessment.

Zappettini, E.O. (2021). Critical and strategic minerals and metals. Situation analysis and classification methodology for the Argentine Republic. Argentine Mining Geological Service.

Exploring Sustainable Critical Mineral Production in Central Appalachia: A Pathway to Economic Revitalization & Environmental Justice

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Keywords: critical minerals, sustainability, environmental justice, circular economy

Abstract

The Evolve Central Appalachia (Evolve CAPP) project team was formed to explore the sustainability of critical mineral production within the Central Appalachian coal basin, spanning Virginia, West Virginia, Kentucky, and Tennessee in the United States. The initiative is evaluating the rare earth and critical mineral resource potential essential for powering clean energy technologies, while fostering a circular economy throughout the energy transition. Opportunities are being sought to address environmental justice, workforce development and responsible sourcing. By promoting greater resource utilization, the project is identifying downstream value-added industries, further fostering economic revitalization in the region.

Exploration and Mining of Critical Raw Materials in the Erzgebirge Region, Germany: Evaluation and Recommendation for Social Sustainability

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Keywords: Erzgebirge, Critical Raw Materials, Exploration, Mining, Questionnaire Survey, Interview, Social Sustainability

Abstract

The Erzgebirge region, which straddles the border between Germany and the Czech Republic, has a long mining history and is well-known for its wide variety of natural resources, including critical raw materials crucial to the digital and green economies and high-tech industry. Nonetheless, the region is home to a sizeable population with a rich cultural and historical past mining, and ongoing mining and exploration operations may negatively impact the views of the locals. Maintaining responsible and ethical processes for the rights, interests, and welfare of residents, workers, and pertinent stakeholders is necessary to ensure positive social impacts on the communities and stakeholders affected by exploration and mining activities. Additionally, it is critical to balance the need for economic growth brought about by resource extraction and society's responsibility to lessen negative consequences and promote positive contributions.

This research investigates the social sustainability of critical raw materials' exploration and mining in the Erzgebirge region by developing and implementing questionnaires, surveys, and interviews focusing on various facets of social domains. The geographic information systems (GIS)-based questionnaire is used to create a public survey that asks about the acceptability of mineral industries, opinions on the pros and cons, and the effects of mineral development on local communities' social cohesiveness. Moreover, another questionnaire is being used to interview mining industry-related professionals in the region. Regression models, content analysis, and GIS are used in data analysis and evaluation to find issues and viewpoints and assess them in relation to factors not confined to location, landscape usage, and the region's inherent susceptibility. A recommendation to support the social licence to explore (SLE) or operate (SLO) has been made based on the findings with the goal of lowering significant business risks in the region's mining and exploration industry.

The Exploitation with a View to Sustainability of Critical Raw Materials from Old Mining Landfills: Analysis of the Possible Recovery in some Mining Areas of the Western Alps

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Keywords: rare earths, critical raw materials, environmental and mining sustainability, mining landfill

Abstract

The ecological transition has opened up new horizons and a new approach to research and the sustainable use of raw materials and the EU intends to ensure a secure supply of critical raw materials in the near future.

According to the United States Geological Survey, global reserves of rare earths are quantified at 110,000,000 t. Of these reserves, the probable contribution that would be made in a logic of environmental and mining sustainability linked to the exploration of critical raw materials in mining waste or in existing deposits exploited for the extraction of other industrial minerals was not considered.

The paper aims to map and characterize some lithologies, analyzing the concentration of critical raw materials and in particular of rare earths (REEs) in the specific context of the Western Alps. They are often associated in small quantities with deposits of monazite and bastnaesite, in some cases they can be found associated with radioactive elements such as thorium and radium, in still others within deposits of kaolin sands, the genesis of which can be identified by processes of meteoric alteration or by alteration of granitic, porphyritic or volcanic complexes of Hercynian age.

Scientific literature gives us, for example, the presence of REEs in rock samples taken from the granite massif of the Biella area with concentrations that vary from a minimum of 124.81 ppm to a maximum of 266.97 ppm. Cerium alone varies from a minimum concentration of 30.9 ppm to a maximum of 168.1 ppm.

Based on the examples discussed in the paper, considerations will be developed on the possible exploitation of rare earths from existing mining landfills, as a useful contribution to their supply in the near future.

Rare Earth Elements (REE) and Critical Minerals (CM) in Middle Pennsylvanian-Age Coals and Associated Sediments in the Central Appalachian Basin, Eastern U.S.A.

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Keywords: Central Appalachian coal basin, critical minerals, REE, pXRF, coal underclay

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Abstract

The Central Appalachian Basin (CAB) of Kentucky, Tennessee, West Virginia and Virginia has a long history of coal mining and oil and gas extraction that has empowered the regional and national economies, the development of infrastructure, and a highly trained energy resources work force. As our societal demands for advanced technologies have rapidly increased in recent years, coal-related materials are viewed as an important new unconventional domestic source of critical minerals (CM) that are required for telecommunications, aerospace and transportation industries, electronics, the transition to low-carbon emissions energy production, and many consumer products. Coal-related materials encompass coal, associated sediments, coal mining waste materials, produced waters, and ash residues from coal-fired power plants.

An important objective of the Evolve Central Appalachia Project (Evolve CAPP), sponsored by the U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL) is to assess the quantity and distribution of CM resources in the CAB region. The rare earth elements (REE) are considered highest priority, although other important CM such as niobium, gallium, and zirconium are known to occur in the Middle Pennsylvanian-age coals and sediments.

Working with coal industry partners who provided access to drill cores, coal-related sediments and waste materials, over 600 samples have been collected for laboratory analysis, and over 730 materials have been scanned using portable x-ray fluorescence (pXRF) equipment. The application of pXRF provides the means for real-time semiquantitative analysis of CM content at very close spacings (typically 2–3-inch intervals) along drill core and in-situ channel samples that span the roof, coal seam, and floor rock. The comparison of pXRF geochemical data with laboratory results, geologic data, and downhole spectral gamma logs can provide high resolution input to lithologic and depositional models for future CM resource evaluations.

The preliminary findings show that pXRF is capable of accurately measuring low concentrations of many of the CM with a high level of confidence (Ba, Cr, Ga, K, Nb, Rb, Sr, Th, Y), whereas for others (La, Ce, Co, Mn, Nd, Ni, Sc, Ti, V) the detection limits are very high or spectral interferences increase the uncertainty. Notably, the mean abundances of Y (34 ppm), La (86 ppm), Ga (40 ppm), and V (146 ppm) in coal underclays in the CAB region are up to 7X enriched compared with the overlying coal. These values also exceed the reported concentrations in published reference materials

for upper continental crustal rocks (Rudnick and Gao, 2003), North American Shale Composite (Gromet et al., 1984), and North American coal (Finkelman, 1993). The pXRF data are in part verified by laboratory results that indicate the mean Y abundance (36 ppm) is highly correlated (R2 = 0.807) with total REE (∑REE). The correlation is even higher (R2 = 0.957) with heavy REE (∑HREE). Applying these correlations to the pXRF data for the coal underclays, the mean estimated values for ∑REE+Y and ∑HREE+Y are 270 ppm and 58 ppm, respectively. Although these average values are not considered high, the range of Y measured by pXRF in the coal underclays extended as high as 114 ppm, which would suggest ∑REE+Y equal to 847 ppm. The mean abundances of Zr (192 ppm) and Th (21 ppm) in coal underclays are also enriched compared with the overlying coal and these results likely reflect the presence of resistant detrital heavy minerals such as monazite, xenotime, and zircon in the underclay matrix. Several of the profiled coal seams and associated wall rocks contained thin volcanic ash layers up to 4-5 inches in thickness. The extent to which these ash fall layers provided a source for CM under the paleoenvironmental conditions that resulted in coal deposits in the CAB remains to be fully studied. Continuing investigations in the Evolve CAPP study area will include laboratory determinations of mineralogic and clay compositions, and evaluations of CM geochemical mobility in the coal and coal underclays.

References

Finkelman, R.B. (1993). Trace and minor elements in coal. Chapter 28, In: Engle, M.H., and Macko, S.A., (eds.). Organic Geochemistry – Principles and Applications, Plenum Press. pp. 593–607.

Gromet, P.L., Dymek, R.F., Haskin, L.A. and Korotev, R.L. (1984). The “North American shale composite”: Its compilation, major and trace element characteristics. Geochemica et Cosmochimica Acta. 48: 2469-2482.

Rudnick, R.L. and Gao, S. (2003). Composition of the Continental Crust. In: Holland, H.D., and Turekian, K.K., (eds.), Treatise on Geochemistry. 3: 1-64.

Determining ESG Impacts on the Copper Supply Chain using Risk Assessment Methods

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1. Introduction

The newest inclusion to the critical mineral list, copper, is a crucial metal recognized for its indispensable qualities in electrical and heat conduction. Copper's significance in the development of technology and renewable energy sources over the past few decades has demonstrated its pivotal role in the creation of sustainable and eco-friendly energy alternatives and the mitigation of Greenhouse Gas (GHG) emissions (U.S. Department of Energy, 2023). However, despite copper's essential role in the transition to sustainable energy, the mining industry has encountered numerous battles in the extraction of this valuable material. These challenges stem from the adverse perception of mining and its extensive environmental, social, and human rights impacts. Furthermore, ensuring the survival of copper mining in the future and fulfilling mineral demand will depend on an emerging topic that has initiated the revolution of the traditional sector into a more environment-friendly and transparent industry, it is Environmental, Social, and corporate Governance (ESG).

ESG has become a compliance measuring tool utilized by companies to seek growth opportunities and standardize risk accountability and transparency based on its collective framework that creates, modifies, and implements local, national, and international standards. The identified standards target environmental, social, and governance weaknesses, risks, or issues faced by companies and their projects (van Duurren et al., 2016). Nonetheless, concerns imply that ESG criteria are having a detrimental effect on the mining industry by targeting what fuels the industry and world: ore deposits and their reserves. Therefore, this research focused on answering the following research questions: what are the impacts of ESG on the copper supply chain and how will stricter ESG standards affect future copper production?

2. Materials and Methods

The research employed various methods of data collection to investigate the impacts of ESG on the copper supply chain. Most of the data collected was observational and qualitative as the intake was ESG inputs or standards. The research initially focused on examining the concept of ESG, its emergence, and its significance across various industries, including the mining sector. Then, a literature review was conducted to establish a foundation for the research by understanding which questions have already been addressed and identifying remaining gaps.

Third, the copper supply chain was dissected to showcase the stages needed from the identification of a copper deposit to the recycling of the goods produced from the copper mined.

Additionally, the copper supply chain was connected to ESG by collecting and analyzing current local, national, and international environmental, social, and governance standards and matching the standard to its respective copper supply chain stage. The effect of the standard was determined by evaluating risk mitigation, project improvements, number of injuries/fatalities, community acceptance, and more. Industry compliance was measured by utilizing active Arizona copper mines as case studies and determining compliance by analyzing yearly sustainability reports, ESG ratings, processes for achieving ESG goals, and whether goals were met or not. Moreover, interviews were conducted with mining professionals who integrate and implement ESG principles into their daily responsibilities. The interviews presented a better understanding of how ESG is incorporated in real mining settings, how feasible it is to enforce stricter standards, and how they believe ESG is affecting their abilities to complete their work. Lastly, based on all the information gathered, conclusions were drawn about the effect of stricter ESG standards on the future copper supply chain (its production, projects, permitting, and more).

3. Results and Discussion

The collected data demonstrated that ESG overall positively impacts the copper supply chain by ensuring compliance with federal, state, and community regulations as well as increasing production and project viability. However, the fulfillment and continuation of this impact will depend on the industry's approach to implementing ESG, ensuring fruitful community engagement, establishing sustainable practices, optimizing projects, and administering a competent risk assessment program.

Further, most companies evaluated for the case studies have standardized ESG commitments and practices. A trend was observed such that profitable and established companies were more flexible in the addition of ESG to corporate approaches and regulations. These companies' resources and financial conditions gave them an advantage in altering practices and implementing new regulations to achieve compliance. Yet, companies with new or developing copper projects were more resilient in the execution of ESG in their mining operations and exploration. These companies were able to establish a concrete foundation from the initial stage which prevented the need to alter rooted operational behaviors or practices. Companies with new copper projects were more effective in communicating with communities and securing a positive relationship through the early formation of a community engagement plan. They were able to recognize and implement community expectations into their mine design and planning to create a sustainable and community-friendly operation.

However, despite all efforts used to create and implement an ESG framework, companies are facing pressure from stakeholders and the government to eliminate and engineer safer mining practices. According to the interviewed industry professionals, a concise and specific ESG framework is needed in the mining industry to create structure and organization because companies are uncertain of what they need to do at a baseline level. Companies are relying on consultants,

organizations, and their knowledge to determine whether their monitoring and risk-solving strategies are being done properly. It is difficult to navigate and follow rules that provide a lot of gray areas and require the guidance of others since interpretation can lead to variations on what companies believe they need to do and their actions. Overall, the interviewees believe that stricter ESG is necessary to help companies understand what is expected of them and to know all the responsibilities they have while not seeming too concerned about the effect on copper production. Ultimately, the competency of the risk management program is determined by its effectiveness in preventing, mitigating, and resolving site-specific challenges. The investment for the creation of an adequate risk management system may be expensive; however, it is vital for the development of long-term solutions. This would be most beneficial for copper projects that have an extensive mine lifetime. Yet, companies should develop effective and resilient risk management systems for any project even if it costs a bit more than short-term solutions as short-term solutions require frequent fixtures. In the future, stricter ESG standards will be developed to prevent and mitigate expected project risks but, in the process, it will limit mine operations by extending permitting waiting time, increasing qualifications for new projects, and so on. Companies that are unable or unwilling to adopt ESG will not persist in the future as ESG is an investment specification. If companies are required to increase the quality of their mining planning and risk management to prevent project risks, investments will be necessary as projects will become more economically inviable.

4. Conclusions

As previously mentioned, copper is the driving force to a functioning modern society, given its essential role in facilitating electricity, powering appliances, and enabling the operation of vehicles to improve societal lives. The demand for copper is expected to increase exponentially due to the rapid development of renewable energy sources required for the addressing of current environmental concerns such as climate change and contamination of resources. However, as accessible and economical mines are drained of their copper ores, the industry will have to turn to more invasive practices to reach challenging ore deposits leading to more negative environmental impacts including excessive energy requirements needed to power equipment, extreme water usage despite potential water scarcity, and a massive generation of waste (Valenta et al., 2019).

To prevent negative environmental and social impacts, an accountable system needs to be universally adopted by the mining industry to help guide companies with current and/or future copper projects to ensure the health and safety of the world. ESG will facilitate the risk by ensuring companies are preventing hazards before they surface, companies are being held responsible for operational damages to communities and nearby resources and increasing the criteria necessary to approve mining projects. ESG majorly impacts the industry and copper supply chain by improving issues and making sure unsolved hazards are being fixed and monitored such as abandoned mine waste sites. ESG frameworks target each stage of the copper supply chain by listing requirements needed to prevent and mitigate risks in order to optimize the efficiency and renewability of the tasks needed to complete the stage. Yet, some disadvantages of ESG include restricting and extending permitting waiting periods and increasing project qualifications for approval which lead to downtime and require expensive alternatives and solutions to reaching net- zero goals.

The data collected from the interaction between standards and copper supply chain stages, interviews with mining experts, and current Arizona copper projects demonstrated that ESG is positively impacting the supply chain and industry. ESG is building a stronger and narrower path towards changing the way mining is being conducted and straying from traditional harmful practices. ESG allows companies to understand regulations that are being created based on public perspectives and testimonies on challenges that mining projects pose to their well-being and the fulfillment of their universal rights. Overall, ESG will help guide the mining industry in its journey toward creating feasible and responsible copper projects to meet future copper demands. This research can be further progressed by creating a standardized ESG framework for the mining industry, simulating the impacts of stricter ESG on the copper supply chain, and analyzing non- ESG-supportive company's survival in the future.

5. Acknowledgements

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6. References

Valenta, R.K., Kemp, D., Owen, J.R., Corder, G.D. and Lebre, E. (2019). Re-thinking complex orebodies: Consequences for the future world supply of copper. Journal of Cleaner Production. 220: 816-826.

Van Duuren, E., Plantinga, A. and Scholtens, B. (2016). ESG Integration and the Investment Management Process: Fundamental Investing Reinvented. J Bus Ethics. 138: 525-533.

U. S. Department of Energy (2023). Critical Materials Assessment. Retrieved from: https://www.energy.gov/sites/default/files/2023-05/2023-critical-materials-assessment.pdf

Mine Closure

Impact Assessment of Mine Closures: Towards a Just Post-Mining Transition

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Keywords: mine closure; impact assessment; post-mining transition; sustainable resource management

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Abstract

The impacts of mining extend beyond its active phase, persisting long after the mine is closed and causing substantial alterations to the environment, local communities, and economic landscape. Typically, impact assessments have been conducted during the early stages of a mining project, often overlooking long-term consequences. Therefore, there is a need to understand and address the broader implications of mine closures to ensure fairness and equity in the transition period after the closure of mines. This requires a comprehensive assessment process, enabling the development of strategies to mitigate negative impacts and maximize positive ones. However, an approach to analyze the impacts of mine closures is lacking, a gap our study addresses. This research aims to achieve a dual purpose: firstly, to identify and classify the positive and negative impacts arising from mine closures and secondly, to evaluate their significance through expert analysis. This research intends to assist mining companies, governments, and other stakeholders in planning and managing post-mining transitions.

Sustainable Rehabilitation of Berg Aukas Abandoned Mine Site, Grootfontein Area, North Central Namibia: A Case Study

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1. Introduction

The issue of abandoned mine sites in Namibia is a major environmental and socio-economic problem for the mining industry, communities, and government. This study is aimed at characterising the Berg Aukas abandoned mine site, a former Pb-Zn-V producer, by developing a hazard scenario that can be used to prioritize its remediation. The Berg Aukas mine site once served as a mining town, where Pb, V, and Zn ores were mined and roasted on site until 1979. Roasting ores produced an unintended hazardous risk in the surrounding area. The principal objectives of this paper are to expand the knowledge on the extent of the contamination of soils with heavy metals and the surrounding local environment, and to determine holistically the effect of ore mining and its process on the environment. The trajectory of sustainable rehabilitation of Berg Aukas abandoned mine site is to return the mine site to a condition that will not pose a hazard to public health and safety, achieve conditions that support wildlife habitats, create a self-sustaining vegetation community, enhance the visual appearance of the area to its pristine or close to its natural form.

2. Berg Aukas Abandoned Mine Site Characterisation

Abandoned mine site characterisation identifies the hazards it poses. The key criteria for the characterisation of abandoned mine sites are to evaluate their condition in terms of their physical and chemical stability, public health and safety risks, ecological risks, and risks to ecosystem services. The historical mining and processing of Zn -Pb -V ores at Berg Aukas left large amounts of various waste (slag, tailings, waste rocks), open shaft No.1, central open pit, northern open pit, old entrance ramp, building concrete structures of the Kiln, old processing plant, and the remnant of mine offices.

3. Sampling Methodology

The Berg Aukas abandoned mine site has been intensively sampled for soils, mine waste, slags, plants, and vegetation; this geochemical survey randomly picked 14 soil samples.These samples were collected from the first 5 cm on the surface with organic matter cleared away. At a collecting point, a sample consisted of soil taken at four points of 1 m. The sample was then homogenised to give a good representative of the sampling spot. Approximately 0.5 kg of each sample was sieved to < 2 mm upon sampling. A fraction of the < 2mm sample was sieved to 180 µm and then used for analysis.

A total of six tailings samples were obtained by a hand-drilling auger with inner diameter of 10 cm. The tailings material was sampled down to a depth of 2.4 m, and the reddish colour of the material indicated oxidation down to this depth. The two tailings dumps have a volume of 343, 500m³ and they are 15 m high.

The slag deposit is located within the central mining area. The surface of the slag deposit was covered by a mixture of concrete and slag, whose surface was estimated to be 35 200 m². Seven slag samples were collected to represent the principal types of materials deposited on the Berg Aukas slag dump. Each slag sample was divided into several parts (i) an aliquot of sample was embedded into an epoxy resin and prepared as a polished thin section for microscopic observations, (ii) the remaining part of the slag was crushed using a jaw crusher to < 4 mm and was pulverized in an agate mortar and used to determination of phase composition and bulk chemistry.

The plant leaves were randomly collected from the plants in the vicinity of ore mining and smelter complex area. One grass sample was collected from the top of the slag dump which was eaten by local livestock. The grass and tree leaf samples were thoroughly washed in abundant tap water and rinsed with distilled water to eliminate any surface contamination. Then, they were air-dried and stored in paper bags.

All samples were analysed by using X-ray fluorescence (XRF) and X-ray diffraction (XRD) and were also investigated using Scanning electron microscopy energy-dispersive spectroscopy (SEM-EDS).

3. Results and Discussion

The study's analytical results show that parts of the soil and vegetation in the Berg Aukas area were severely contaminated by arsenic, cadmium, copper, lead, and zinc. The contamination traces back to historic ore roasting and wind-blown dust from slag dumps and tailings.

Heavy metals, like arsenic, cadmium, copper, lead, and zinc, can enter the human body through drinking water or consuming crops grown on polluted land. These metals are toxic and contribute to environmental hazards (in the case of Berg Aukas), leading to oxidative stress in cells and various health issues, including brain damage, cancer, and developmental abnormalities (Mapani et al., 2010). Dumpsites (tailings dumps, slag dumps) frequented by scavengers pose a risk as materials from these sites can end up as animal food, creating vectors for pests and diseases. Plants absorbing high concentrations of heavy from contaminated soil pose human health risks, especially when consumed, as these metals accumulate in tissues (Monib et al., 2024).

3.1 Risk Analysis and Assessment

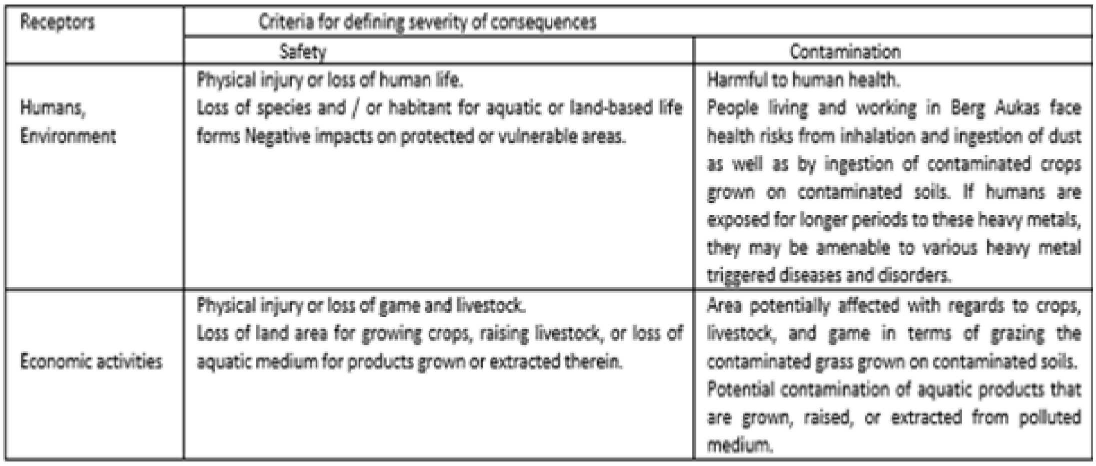
Risk assessment involves physical safety and chemical (contamination) safety, which includes looking at the exposure pathways, which will bring the receptor into direct contact with the source of contamination: and the source of contamination if present in concentrations that will generate undesired effects on receptors.

3.2 Berg Aukas mine site Hazard Scenario

The following hazards were identified at Berg Aukas mine site, these include the two tailings dumps, the slag dump, subterrain adit, central open pit, old ore processing plant kiln, old processing plant and old mining offices.

The findings of this research study identified some environmental risks, of which some were considered significant health risks at the Berg Aukas mine site, as shown in Table 1, which is an integrated table that produces a single matrix that contains all the risks (safety risks and contamination risks) present in Berg Aukas mine site under assessment.

Table 1.: Criteria for defining the severity of consequences.



Receptors	Criteria for defining severity of consequences	
	Safety	Contamination
Humans, Environment	Physical injury or loss of human life. Loss of species and / or habitant for aquatic or land-based life forms Negative impacts on protected or vulnerable areas.	Harmful to human health. People living and working in Berg Aukas face health risks from inhalation and ingestion of dust as well as by ingestion of contaminated crops grown on contaminated soils. If humans are exposed for longer periods to these heavy metals, they may be amenable to various heavy metal triggered diseases and disorders.
Economic activities	Physical injury or loss of game and livestock. Loss of land area for growing crops, raising livestock, or loss of aquatic medium for products grown or extracted therein.	Area potentially affected with regards to crops, livestock, and game in terms of grazing the contaminated grass grown on contaminated soils. Potential contamination of aquatic products that are grown, raised, or extracted from polluted medium.

It is evident from the risk assessment that the Berg Aukas mine site is classified as a MEL -Class1, as per the Risk Assessment Manual (SAIEA, 2010a) that was assessed and found to have at least two 'significant risk' to humans, environmental, health, safety, and poses a risk to economic activity, therefore classified as a Mining Environmental Liability (MEL).

Contamination of soils northeast of the mining area poses a significant problem. The local population grow maize, cassava, potatoes, and other vegetables. Regular consumption of such plants will result in health problems. It is also recommended that most of the agricultural production of vegetables be transferred to the southeast or northwest of the town where the dust fall is very low due to the sheltering function of the mountain range. As the severe contamination is focused on the closer vicinity of the mining and smelter complex as well as the tailings dump, a distance of at least 2 km to those sites is recommended until complete remediation is done.

3.3 Selection of sustainable rehabilitation methods for the BERG AUKAS mine site.

Sustainable rehabilitation and closure is modeled to achieve realistically implementable scenarios.

To minimize environmental impact, these two tailings facilities would need to be fenced off to prevent unlimited access to these tailings dumps. To prevent further tailings material spillage into adjacent ephemeral streams, retaining walls are to be constructed on the eastern part of the tailings dumps. As to the remediation of the slag dump, phytocap the whole the slag dump and the highly contaminated central part of the ore processing plant area using a layer of uncontaminated soil from the southwestern part of the mining area. Finally, the re-establishment of vegetation on top it is therefore, recommended that the same vegetation (plant species called dononaea viscosa variety Angustifolia) will be used on top of the slag dump coverage, because of its tolerance to potentially toxic elements (PTEs). To rehabilitation the infrastructure (old mining offices, old processing plant, and old power station) consideration should be given to those with future use and those that pose health and safety risks. The latter must be demolished, and the foundation should similarly be demolished, using hydraulic hammers, and the rubble removed and buried onsite or be dumped to cover the slag dump. The rehabilitation solution of the mountain range where (No.1 Shaft and the two open pits) is to be fenced off at a sufficient distance from the mountain slope area. The unbarricaded adit presents hazards such as rotten structures, falling from walls, the presence of animals like bats and snakes, and presence of toxic gas. Adit is also characterized by darkness and low air circulation, which might lower a person's orientation ability. Therefore, this adit should be barricaded using steel grate closure.

3.4 BERG AUKAS mine site rehabilitation closure cost estimates.

This research used two rehabilitation cost estimates, the Nevada Standardized Reclamation cost estimator and (Golder Associates Africa Pty Ltd, 2019), based on South African Master Rate estimates and applying the Namibian Consumer Price Index (CPI) for 2022. The workbook for each site provide a list of current equipment rates and labour costs used in the calculation and a detailed, site-specific estimate of cost under each of the following headings: equipment and labour, infrastructure decommissioning, physical earthworks, reclamation, project management, monitoring and reporting, mobilization, and demobilization, staffing support, transition and phase monitoring. Equipment hourly rate that considers undercarriage/tyre depreciation, general equipment maintenance, and fuel cost per hour. The labour hourly rate considers hourly labour wage, fringe benefit, retirement Medicare, unemployment insurance and workman's compensation cost per hour.

The results of these two Rehabilitation cost estimators are almost the same with the Nevada Model yielding U$ 4.74 million and South African Model U$ 5.07 million. Nevada Standardized Reclamation Cost Estimator cost estimates are 6 % less than the South African Master Rate Rehabilitation Cost Estimator cost estimates.

4. Conclusion

The historical mining and processing of Zn -Pb -V ores at Berg Aukas left large amounts of various wastes (slag, tailings, waste rocks,), open shaft No.1, central open pit as well as a northern open pit, old entrance ramp, building concrete structures of the Kiln, old processing plant, and the remnant of mine offices. The study found that the prominent risk is derived from the two tailing dumps, the slag dump, and the old ore processing plant. Sampling results show that parts of the soil and vegetation in the Berg Aukas area are severely contaminated by As, Cd, Cu, Pb, Hg, and Zn. The major contamination risk derived from the historic ore roasting and windblown dust from the slag dump and the two tailings dumps, and the second risk is from two open pits and the subterranean adit, which are unfenced and pose a hazard of falls from its high steep walls which is a risk to people, livestock and game and the movement of particulate toxic gasses that could affect persons (inhaling) toxin gasses.

Sustainable rehabilitation and closure intervention was proposed and modeled to assist the abandoned mine site with feasible and realistically implementable scenarios. The proposed rehabilitation for the Berg Aukas mine site is phytocapping the slag dump with the uncontaminated soil gravel, demolition of the old ore processing plant, old processing plant, and fence off the two tailings dumps and the mountain range. The rehabilitation cost estimates for these domains were also determined by applying two rehabilitation cost estimates the Nevada Standardized Reclamation cost estimator based on South African Master Rate estimates and applying the Namibian Consumer Price Index (CPI) for 2022. Cost estimation of these practical rehabilitation strategies was recommended to ensure that low-cost strategies are implemented at the Berg Aukas mine site.

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6. References

Ettler, V., Cihlová, M., Jarošíková, A., Mihaljevič, M., Drahota, P., Kříbek, B. and Mapani, B. (2019). Oral bioaccessibility of metal(loid)s in dust materials from mining areas of northern Namibia. Environment International. 124: 205–215.

Ettler, V., Jarošíková, A., Mihaljevič, M., Kříbek, B., Nyambe, I., Kamona, F. and Mapani, B. (2020). Vanadium in slags from smelting of African Pb-Zn vanadate ores: Mineralogy, extractability, and potential recovery. Journal of Geochemical Exploration. 218: 106631.

Ettler, V., Johan, Z., Kříbek, B., Šebek, O. and Mihaljevič, M. (2009). Mineralogy and environmental stability of slags from the Tsumeb smelter. Namibia. Applied Geochemistry. 24(1): 1–15.

Ettler, V., Mihaljevič, M., Jarošíková, A., Culka, A., Kříbek, B., Majer, V. and Kamona, F. (2020). Vanadium-rich slags from the historical processing of Zn–Pb–V ores at Berg Aukas (Namibia): Mineralogy and environmental stability. Applied Geochemistry. 114: 104473.

Golder Associates Africa Pty Ltd. (2019). Consolidated Financial Provisioning Report. Shiseido Group (Vol. 2).

Kamona, A.F. and Günzel, A. (2007). Stratigraphy and base metal mineralization in the Otavi Mountain Land, Northern Namibia-a review, and regional interpretation. Gondwana Research. 11(3): 396–413.

Kříbek, B., De Vivo, B. and Davies, T. (2014). Special Issue: Impacts of mining and mineral processing on the environment and human health in Africa. Journal of Geochemical Exploration. 144: 387–390.

Mapani, B., Ellmies, R., Kamona, F., Kříbek, B., Majer, V., Knésl, I. and Mbingeneeko, F. (2010). Potential human health risks associated with historic ore processing at Berg Aukas, Grootfontein area, Namibia. Journal of African Earth Sciences. 58(4): 634–647.

MME. (2007a). Human Health Risks Associated with Historic ore processing at Berg Aukas, Grootfontein Area, Namibia.

MME. (2007b). Soil contamination at Berg Aukas - Implications for further land use.

MME. (2013). Follow up study on the 2008 Berg Aukas contamination.

SAIEA. (2010a). 4.4.1 simplified risk assessment.

Developing a Strategic Plan for Resilience Management in Post-Mining Projects

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1. Introduction

Surface lignite mining is an activity of crucial importance for power generation. As a lignite mine enters the closure phase, a transformation plan is initiated to rehabilitate and repurpose the use of the land that is disturbed by long-term extractive operations. The post-mining transformation projects aim to upgrade the disturbed mine lands, restore the ecosystems, and introduce socio-environmentally friendly solutions and logistics to support the transition to sustainable development and circular economy (Pactwa et al., 2020; Pavloudakis et al., 2023).

Essential activities of such projects are the redesign of land uses, restoration of terrain topography, biodiversity, land fertility, and detoxification of soils and waters, and on top, mitigation of the environmental and social impacts at the greater area of a mine complex (McCullough, 2016; Kivinen, 2017; Pavloudakis et al., 2022). In this context, the resilience of post-mining land(s) constitutes a challenging issue of high criticality. The term resilience refers to human interventions and engineering measures required to reduce the geoenvironmental vulnerabilities of the mined areas caused by the intensive extractive operations and also to enhance sustainability and enable mechanisms of society preparedness against natural hazards and climate extremes (floods, earthquakes, subsidence, soil erosion, etc.) (Fekete et al., 2014; Spanidis et al., 2021).

The activities involved in engineering and constructing resilience measures and related infrastructures and obtaining stakeholders' consent on these interventions could form part of an integrated strategy within a post-mining transformation project execution plan that embodies various managerial, technical, socio-economic, and administrative aspects. Alternatively, the resilience activities could be incorporated into a customized framework designed to develop an integrated, efficient, and effective resilience management system addressing high readiness and responsiveness purposes tailored to the specific needs of the mine in question.

In any case, the resilience frameworks/projects must be based on a well-structured and multidisciplinary strategy. This paper (a) analyzes a resilience strategic management plan as a set of processes, adaptable in the context of a typical mine transformation project, and (b) represents the model of such a strategic plan structure, elaborated by utilizing the IDEF0 functional design language. A brief discussion is provided, with the main conclusions and recommendations for future research.

2. Materials and Methods

The methodology adopted for the design of a resilience strategy plan was organized in two steps: (a) an Analysis of the content of a typical resilience project with identification of the main processes and inherent activities. As a case study, the lignite mine of Megalopolis (Peloponnese, Greece) was used, which is under sustainable transformation, and (b) the Design and Validation of the main processes (or functions) with any other data, materials, and infrastructures required for the representation of the functionality of these processes. The methodology was elaborated in close cooperation with managers, operators, and engineers possessing in-depth experience in the Greek lignite mining industry and related operations.

3. Results

Analysis: The content of a typical post-mining resilience strategic plan was thoroughly assessed. Three (3) main processes (key functions), along with each process's inherent activities, were identified as the most representative ones for the lignite mine in question.

P(1.0)-Definition and Scoping of Resilience Project: P(1.1): Situational analysis of the mine; P(1.2): Assessment of historical records and related risks for the natural hazards (at the greater area of the mine); P(1.3): Definition of the content and scope of the resilience project activities; P(1.4): Setting up the resilience engineering basis and elaboration of preliminary/basic engineering studies; P(1.5): Cost estimation and organization of the project and construction management system.

P(2.0)–Stakeholders’ Engagement: P(2.1): Organization and execution of the stakeholders' engagement and management framework; P(2.2): Project communication and conducting public consultation meetings; P(2.3): Adaptation of stakeholders’ opinions and recommendations in the resilience engineering basis of design and technical specifications; P(2.4): Consideration of the regulatory and legislative provisions.

P(3.0)-Engineering and Construction of Resilience Infrastructures: P(3.1): Performing the detailed studies for the resilience engineering measures and interventions and preparation of the tender packages; P(3.2): Tendering and contractors evaluation and selection; P(3.3): Erection/construction of resilience measures and infrastructures; P(3.4): Preparation of the time-schedule for the resilience system implementation; P(3.5): Establishment of post-mining resilience policies and emerging procedures to prevent and handle the natural hazards risks and related impacts.

Design and Validation: The post-mining resilience projects are multidisciplinary frameworks of high complexity and, as such, require the involvement of stakeholders and personnel from various fields of science and technology and a combination of effective and resilient against natural hazards methods for the sustainable transformation of the mined lands. In this regard, for the design of a resilience planning project strategy against natural hazards, the IDEF0 method has been applied.

IDEF0 is a function modeling method and systems engineering language with extended references in the functional analysis and design of industrial management and manufacturing systems, business process modeling, science and R&D frameworks, and complex engineering projects (Chen et al. 2020, Spanidis et al., 2022). IDEF0 is a top-bottom task ontology, combining graphics and text entities. The syntax of the method represents (a) box diagrams to define processes (or functions), (b) arrows to represent data flows, interlinks, and feedback loops, and (c) entities, which every single process requires for its application/deployment. These entities are Inputs and Outputs (data and/or objects), Controls (decisions, legislative constraints, time plans, contracts, budgetary estimations), and Mechanisms (materials, resources, knowledge, specifications, etc.).

The IDEF0 models, also known as ICOM workflow models, represent the synthesis of the structure and functionality of ICOM entities. The top event of an ICOM model reflects the primary process of the analysis symbolized as A-0, under which the constituent processes are merged to a lower and more detailed level of analysis. Each constituent process can be further analyzed in the hierarchy, and so forth. Figure 1 reflects the top event, and the general hierarchical structure of the analysis performed. Figure 2 reflects the detailed IDEF0 model. It is noted that some ICOM entities may be identical for more than one process as the workflow runs from one process to another. The validation of the analysis and the outlined IDEF0 model was carried out in two (2) workshops, in which various critical improvements and revisions on the structure and functionality of the processes identified were performed in cooperation with the mining experts, site managers, and operators.

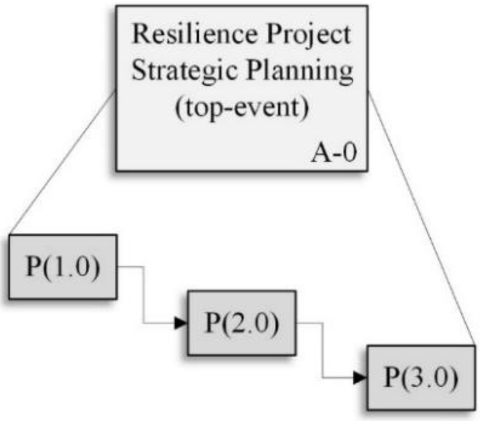

Figure 1. The IDEF0 model (Structure & Hierarchy)

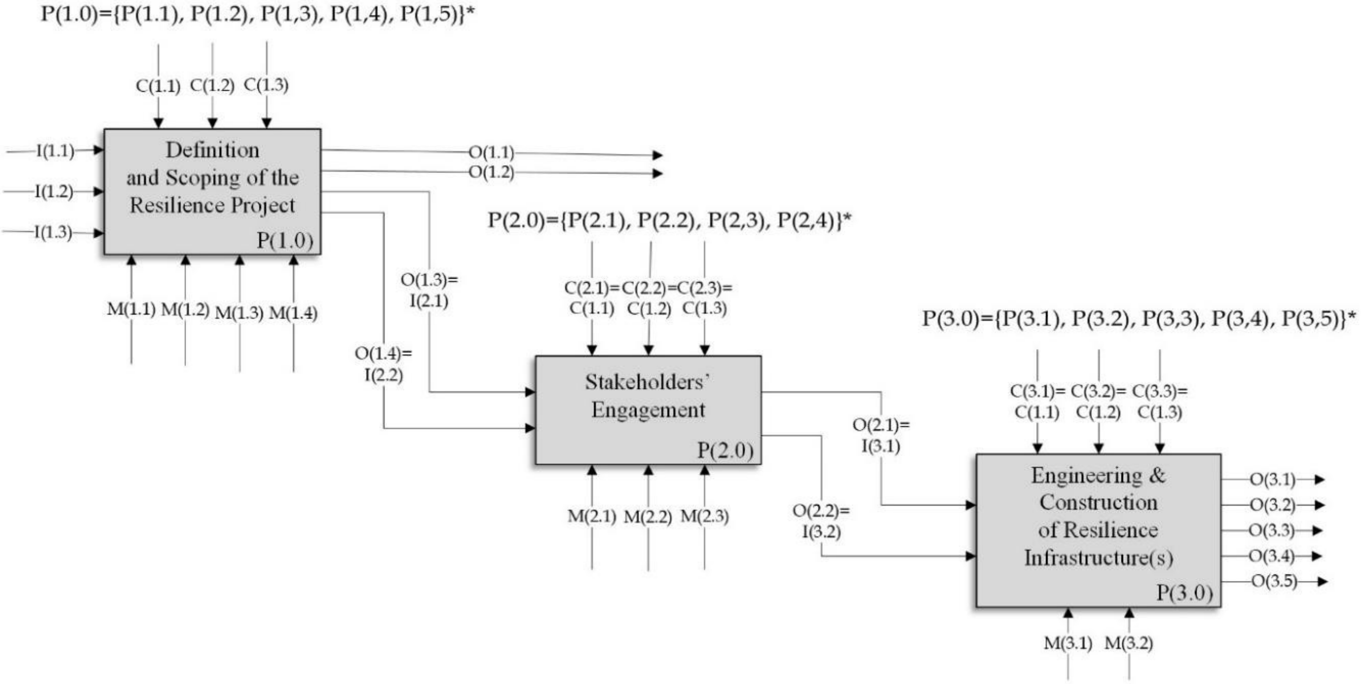

Figure 2. IDEF0 model design for the post-mining resilience project planning.

ICOM entities-P(1.0): I(1.1): Policies for the management of climate change and people's protection from natural hazards; I(1.2): Policies for repurposing and restoration of ageing/closing mines; I(1.3): Decision taken for the mine transformation; O(1.1): Identification of the resilience project strategic goals, means, and actions required; O(1.2): Resilience project definition (managerial and technical content); O(1.3): Natural hazards risk assessment; O(1.4): Feasibility analysis with cost estimation(s) of the resilience project; C(1.1): Resilience project time plan; C(1.2): Budgetary limitations; C(1.3): Legislative and regulatory constraints; M(1.1): Historical data for the natural hazards occurrence at the mine's region; M(1.2): Methods for the transition to circular economy and sustainability; M(1.3): Methodologies and standards for the natural hazard risk assessments; M(1.4): Analysis of post-mining logistics networks/facilities/infrastructures.

ICOM entities-P(2.0): I(2.1)=O(1.3); I(2.2)=O(1.4); O(2.1): Definition of Stakeholders' opinion(s); O(2.2): Register of the mine specific Social and Environmental commitments; C(2.1)=C(1.1); C(2.2)=C(1.2); C(2.3)=C(1.3); M(2.1): Performance standards of international funding organizations (e.g. European Bank for Reconstruction and Development-EBRD); M(2.2): Stakeholders engagement and public consultation practices and procedures; M(2.3): Project communication informative material.

ICOM entities-P(3.0): I(3.1)=O(2.1); I(3.2)=O(2.2); O(3.1): Engineering and design for the erection/construction of resilience infrastructures; O(3.2): Tender Packages; O(3.3): Management and construction plan for the resilience project execution; O(3.4): Development of Quality/HSSE management systems; O(3.5): Supervision of resilience measures construction; C(3.1)=C(1.1); C(3.2)=C(1.2); C(3.3)=C(1.3); M(3.1): Specifications for the engineering, construction, and landscape/landforms restoration; M(3.2): International standards and best available practices for the closing, reclamation and restoration of opencast coal mines.

4. Discussion and conclusions

The assessed resilience management strategic plan and its constituent elements in this paper provide a generic viewpoint on how a post-mining resilience project can be represented and composed as a system of interrelated functions using the simple, easily developed, and low-cost tool of the IDEF0 modeling language. There are many different methods of strategic planning for large-scale and high-complexity projects and business frameworks, such as SWOT analysis, methods for multi-criteria decision-making, risk-based analysis tools, etc. Every method, however, reflects the preference of researchers to utilize a tool that enables a better formulation of an effective, feasible, and well-presentable model to reflect the solution to the strategic problem in question.

The graphical flexibility of the IDEF0 method allows (a) investigation of the content of resilience activities within, or in parallel to, other post-mining transformation projects and initiations that are developing at the mine region, (b) incorporation of stakeholders' proposals and expectations, reported in public consultation meetings, (c) analysis of the resilience project execution, and (d) various managerial and technical readjustments in the content (inherent activities) and functionality of the identified processes, along with the essential resources and mechanisms required for the strategic plan functionalization. In addition, IDEF0 offers the basis for analysis, at a higher level of detail, of the resilience planning processes and the interrelationships among them. As a proposal for further research, the combination of the activities of the IDEF0 model with the risks of natural hazards at the mine in question and the integrated and multidisciplinary investigation of the socio-economic impacts due to the large-scale resilience infrastructure(s) implementation can be considered interesting research topics.

5. References

Chen J., Jiskani, I.M., Jinliang, C. and Yan, H. (2020). Evaluation and future framework of Green Mine Construction in China Based on the DPSIR Model. Sustain. Environ. Res. 30: 13.

Fekete, A., Hufschmidt G. and Kruse S. (2014). Benefits and challenges of resilience and vulnerability for disaster risk management. Int. Jour. of Disaster Risk Science. 5: 3-20.

Kivinen, S. (2017) Sustainable post-mining land use: Are closed metal mines abandoned or re-used space? Sustainability, 9(10): 1705.

McCullough, C.D. (2016). Key mine closure lessons to be learned; Australian Centre for Geomechanics: Perth, Australia. pp.319–332.

Pavloudakis, F., Roumpos, C. and Spanidis, P.M. (2023). Planning the closure of surface coal mines based on circular economy principles. Circular Economy and Sustainability. 14: 1-22.

Pactwa K., Woźniak J. and Dudek, M. (2020). Coal mining waste in Poland in reference to circular economy principles. Fuel. 15(270): 117493.

Pavloudakis, F, Roumpos, C. and Spanidis, P.M. (2022). Optimization of surface mining operation based on a circular economy model. Circular Economy and Sustainability. 1: 395-418.

Spanidis, P.M., Roumpos, C. and Pavloudakis, F. (2021). A fuzzy-AHP methodology for planning the risk management of natural hazards in surface mining projects. Sustainability. 13(4): 2369.

Spanidis, P.M., Roumpos, C. and Pavloudakis, F. (2022). A Methodology combining IDEF0 and weighted risk factor analysis for the strategic planning of mine reclamation. Minerals. 12(6): 713.

Certification and Ecological Reclamation of Mined Areas: Evolving Standards and Practices for Sustainable Mining

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1. Introduction

Mining activities are essential part of the modern economies, providing critical materials for various industries. However, these activities significantly impact the environment. Recognizing these challenges, ecological reclamation emerges as a critical step towards restoring environmental balance and mitigating the adverse effects of mining. This process involves rehabilitating mined areas to a state that supports a predetermined post-mining land use, aiming for ecological integrity, soil health, and overall ecosystem resilience.

Certification plays a pivotal role in this context, setting benchmarks and guidelines to ensure that reclamation efforts are effective and sustainable. The significance of these certifications extends beyond ensuring adherence to environmental standards; they also contribute to the broader goal of sustainable mining practices. By establishing credibility and trust among stakeholders, certifications encourage responsible mining operations that prioritize long-term environmental and social outcomes. This study aims to explore the evolution of standards for the certification of rehabilitation of mined sites. Through a detailed examination of the most common certifications systems for mine reclamation, the paper will highlight their role in promoting effective ecological reclamation and the challenges and opportunities presented by these evolving standards.

2. Historical Background and Evolution of Certification Systems

Early methods of rehabilitating mined land focused on immediate measures such as applying topsoil and planting fast-growing species to address visible problems such as soil erosion and vegetation loss. While these efforts addressed the immediate impacts of mining, they often overlooked the long-term ecological health and integration of rehabilitated areas into their environment, pointed out that these early measures were simple but inadequate for establishing self-sustaining ecosystems or wider environmental benefits (Lei et al., 2016).

The lack of formal certification initially led to uneven quality of rehabilitation projects. This variability led to the development of certification focused on soil and vegetation stabilisation, which recognised the need to standardise practices but was still limited in addressing ecological functions or long-term sustainability. These limitations highlighted the need for more comprehensive restoration strategies that included restoring native plant communities, wildlife habitats and improving soil and water health. This shift marked a significant evolution towards more holistic and ecologically focused restoration models.

The evolution of certification systems for the ecological rehabilitation of mined areas represents a significant advancement in environmental science, moving from basic reclamation to sophisticated, ecosystem-based strategies. These systems have been crucial in addressing the restoration of ecological functions and biodiversity in mined areas and highlights the shift towards restoring whole ecosystems, rather than just individual elements like vegetation or soil stability (Lei et al., 2016). Certification systems now set standards that promote holistic practices, emphasizing landscape connectivity, habitat diversity, and ecological resilience. The integration of modern ecological principles into certification criteria has improved the effectiveness of mined land rehabilitation (Gastauer et al., 2018). These principles guide the selection of plant species to restore ecological functions and consider evolutionary relationships to enhance biodiversity and resilience. The adoption of these criteria by certification systems ensures that rehabilitation efforts not only promote species richness but also the restoration of complex ecological networks, leading to sustainable outcomes. Furthermore, the role of phytoremediation and soil amendments has become integral to these certification systems, addressing soil contamination issues (Wong, 2003). These systems encourage the use of environmentally friendly methods such as phytoremediation in their standards, specifying criteria for plant selection and soil amendment strategies to ensure effective restoration of soil health and re-establishment of ecosystems.

3. Standards for Ecological Reclamation of Mined Areas

Among the most notable certifications are those offered by the International Standards Organisation (ISO) and the Society for Ecological Restoration (SER). More specifically the ISO 14001, ISO 26000, and ISO 21795 are briefly examined below and compared with these established by the Society for Ecological Restoration (SER). ISO 14001 is a universally recognized standard that outlines criteria for an effective environmental management system (EMS). It provides a framework that an organization can follow, rather than establishing environmental performance requirements. In mine reclamation ISO 14001 helps companies adopt a systematic approach to environmental management, ensuring continuous improvement and compliance with relevant environmental regulations. Moreover, the standard emphasizes the identification and management of environmental impacts, which is crucial in mitigating the effects of mining operations during and after the extraction process.

ISO 26000 provides guidance on social responsibility, offering directions on how companies and organizations can operate in a socially responsible way, which includes environmental aspects. This standard focus on the importance of community involvement and stakeholder engagement, essential for successful mine reclamation as it aligns the restoration activities with community needs and expectations. Additionally, ISO 26000 encourages organizations to prioritize environmental integrity, promoting sustainable practices that are directly applicable to mine reclamation. Both ISO 14001 and 26000 are not specific to ecological reclamation, they provide a framework for organisations to develop and implement environmentally responsible practices. Recent (2021) ISO 21795 standard specifies the framework, and the processes involved in mine closure and reclamation planning for new and operating mines, and it also provide requirements and recommendations on:

- mine closure and reclamation plan objectives and commitments
- technical procedures and techniques
- mitigation of socio-economic impacts
- financial assurance and associated planning
- mine closure and reclamation planning for unplanned closure
- post-closure management plan
- mine closure and reclamation plan documentation

Society for Ecological Restoration (SER) standards present a robust and evidence-based framework to guide restoration projects toward achieving intended goals and address restoration challenges. SER certification criteria and assessment focus on the impact on biodiversity, soil health, and ecosystem resilience. Instead of certifying companies, SER offers a certification program for individuals. The Certified Ecological Restoration Practitioner (CERP) program is designed to certify the knowledge and experience of professionals in ecological restoration. They highlight the role of ecological restoration of mined ecosystems for connecting social, community, landscape, and sustainability goals and promote the establishment of the trust model between industry, government, research and the community.

Moreover, they provide guidance for developing and achieving performance measures based on an established trajectory and develop a culture of continuous improvement that routinely reviews practices and planning, implementation, and monitoring activities. SER certification focuses on ecological integrity, incorporating historical, cultural, and sustainable management considerations (Young et al., 2022). In contrast, ISO certifications, such as ISO 14001 and ISO 26000, provide frameworks for environmental management and social responsibility, respectively while the recent ISO 21795:2021 standard specifically addresses mine closure and reclamation planning.

4. Conclusions - Challenges and Future Directions

Significant progress has been made in the development of certification schemes for the ecological rehabilitation of mined areas. However, as the environmental landscape changes, these systems face complex challenges, highlighting the need for adaptive strategies that incorporate technological and community advances.

Current certification systems must evolve to address the impacts of climate change, which affects plant viability, water availability, and increases weather-related risks. This requires integrating climate resilience into certification criteria, focusing on the selection of robust plant species and strategies that enhance ecological flexibility and resilience. Biodiversity loss, impaired by mining, poses another challenge. Current efforts focus on restoring native vegetation and habitat diversity, but deeper ecological understanding is necessary. The uncertainties of ecological systems and ongoing environmental degradation underscore the need for flexible, adaptive management within certification systems. This should include continuous monitoring and adjustments based on new data and changing conditions, allowing for site-specific adaptations and scientific advancements. The future of certification systems will likely feature greater use of technologies like remote sensing, GIS, and machine learning to monitor progress and assess ecosystem health.

Moreover, increasing community involvement is crucial for aligning rehabilitation with local needs and values. Future systems should emphasize participatory approaches and stakeholder engagement, integrating traditional ecological knowledge to forge effective rehabilitation strategies. As certification systems evolve to incorporate these elements, they will better guide sustainable rehabilitation efforts, enhancing ecosystem and community resilience among environmental changes. The components of such a certification system are shown in Figure 1.

5. Acknowledgements

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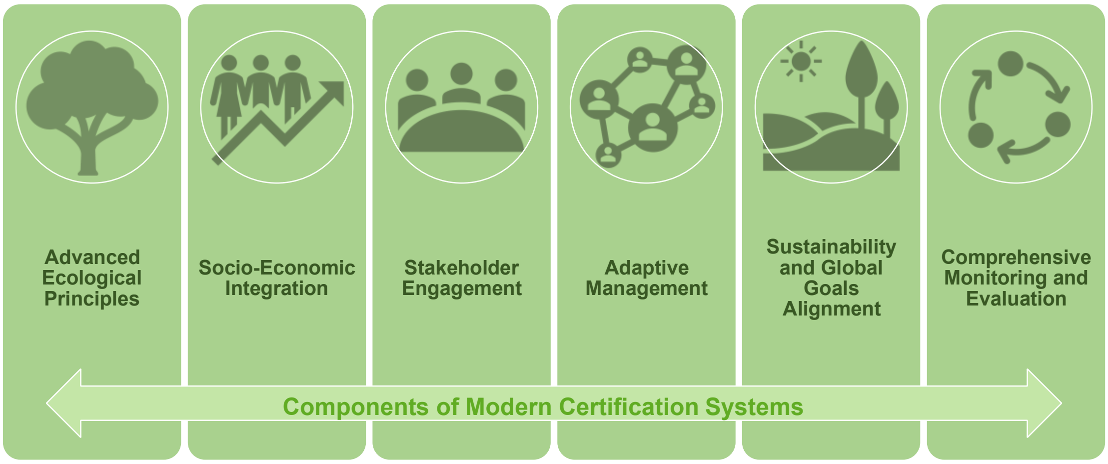

Figure 1. Components of a modern certification system.

6. References

Gastauer, M., Silva, J.R., Junior, C.F.C., Ramos, S.J., Souza Filho, P.W.M., Neto, A.E.F. and Siqueira, J.O. (2018). Mine land rehabilitation: Modern ecological approaches for more sustainable mining. Journal of Cleaner Production. 172: 1409-1422.

International Organization for Standardization (2021a). ISO 21795-1:2021 Mine closure and reclamation planning – Part1 (requirements).

International Organization for Standardization (2021b). ISO 21795-1:2021 Mine closure and reclamation planning – Part2 (guidance).

Lei, K., Pan, H. and Lin, C. (2016). A landscape approach towards ecological restoration and sustainable development of mining areas. Ecological Engineering. 90: 320-325.

Wong, M.H. (2003). Ecological restoration of mine degraded soils, with emphasis on metal contaminated soils. Chemosphere. 50(6): 775-780.

Young, E.R., Gann D.G., Walder, B., Liu, J., Cui, W., Newton, V., Nelson, R.C., Tashe, N., Jasper, D., Silveira, F.A.O., Carrick, P.J., Hägglund, T., Carlsén, S. and Dixon K. (2022). International principles and standards for the ecological restoration and recovery of mine sites. Restoration Ecology. 30(S2): 1-47.

Socio-Economic Impacts and Challenges of Mine Closure and Just Transition in Itabira, Brazil

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Keywords: Mine Closure, Socio-Economic Impacts, Just Transition, Post-Closure, Territorial Governance

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Abstract

Mining operations significantly influence the socio-economic fabric of the regions where they occur, bringing benefits and challenges. While the increase in employment, income, and tax revenues is undeniable (Vivoda et al., 2019), these advantages are often accompanied by environmental degradation, the disappearance of traditional economic activities, increased economic dependency, and increased pressure on local social services (Esteves et al., 2009; Mancini et al., 2018), leading to socio-economic imbalances, discontentment and conflicts. The finite nature of mining exacerbates these issues post-operation, potentially leading to economic stagnation and intensifying social problems (Xavier, 2014; Everingham, 2020).

In the current landscape, we are witnessing a dual phenomenon: the surge in demand for critical minerals essential for transitioning to a greener economy is leading to the opening of new mines, while simultaneously, there is an increasing push to close mines associated with fossil fuel production, such as coal. This scenario will result in a higher number of mine closures. Which must not only address environmental rehabilitation but also ensure a just post-mining transition (Everingham, 2020).

The academic literature on mine closure has predominantly focused on environmental repercussions, with the social dimensions gaining attention only recently (Vivoda et al., 2019; Demajorovic et al., 2022). Some common characteristics identified in mining regions indicate the difficulties for the social impacts of the mine closure process to be included in post- mining territorial development strategies and plans: the fragility of local governance systems and the dominance of the mineral project in the political, economic, and social life (Cole et al., 2020), the low lack of capacity of local governments to plan and address the social impacts accompanying the closure processes and the deliberate attitude of companies in not engaging in closure processes and allocation of adequate resources to enable a just transition (Bainton et al., 2018).

Furthermore, the limitations of local communities in redefining themselves after long periods of economic dependence (Van Assche et al., 2021) and the absence of a positive legacy for the territory that contributes to ensuring its sustainable development based on a diversified economy independent of mining further complicates the transition (Zyvarivadza, 2018). This study focuses on Itabira, a municipality in Minas Gerais, Brazil, which hosts the first large-scale mining project developed and

operated by Vale. With an 80-year mining history and a future closure scheduled for 2041, Itabira presents a critical case for examining the socio-economic repercussions of mine closures. The city's deep-rooted mining identity and economic reliance on this sector pose unique challenges for its post-mining transition. The central research question explores how Itabira's historical context and the social impacts of mining influence the mine closure process. This study examines the critical challenges Itabira faces in navigating its economic and social transition post- mining, offering insights into the broader implications for mining-dependent regions undergoing similar closures.

References

Bainton, N.A. and Holcombe, S.A. (2018). Critical review of the social aspects of mine closure. Resources Policy. 59: 468-478.

Esteves, A.M. and Vanclay, F. (2009). Social Development Needs Analysis as a tool for SIA to guide corporate-community investment: Applications in the minerals industry. Environmental Impact Assessment Review. 29(2): 137-145.

Cole, M.J. and Broadhurst, J.L. (2020). Mapping and classification of mining host communities: a case study of South Africa. The Extractive Industries and Society. 7(3): 954-964.

Demajorovic, J. Xavier, A., Pimenta, A.A.F. and Batteto, R.S. (2022). Social aspects in the process of mine closure: evolution and avenues for future research agenda. In the proceedings of the 15th International Conference on Mine Closure, Australian Centre of Geomechanics. pp. 187-198.

Everingham, J.A., Svobodova, K., Lebre, E., Worden, S. and Owen, J.R. (2020). Mining regions in transition – a global scan. Centre for Social Responsibility in Mining. University of Queensland: Brisbane.

Mancini, L. and Sala, S. (2018). Social impact assessment in the mining sector: Review and comparison of indicators frameworks. Resources Policy. 57: 98-111.

Van Assche, K., Gruezmacher, M. and Granzow, M. (2021). From trauma to fantasy and policy. The past in the futures of mining communities; the case of Crowsnest Pass, Alberta. Resources Policy. 72: 102050.

Vivoda, V., Kemp, D. and Owen, J.R. (2019). Regulating the social aspects of mine closure in three Australian states. Journal of Energy & Natural Resources Law. 37(4): 405-424.

Xavier, L. (2014). Socio-Economic Mine Closure (SEMC) framework: a comprehensive approach for addressing the socio-economic challenges of mine closure. Doctoral dissertation. University of British Columbia, Canada.

Zyvarivadza, L. (2018). Large scale miners-Communities partnerships: A plausible option for communities’ survival beyond mine closure. Resources Policy. 56: 87-94.

Wetbud, a Free Tool for Estimating Wetland Water Budgets

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Abstract

Throughout the United States, there exist hundreds of thousands of former mine lands that now lie idle or abandoned. Once vital sources of raw materials for flourishing industries, these sites now pose potential environmental contamination risks. Wetland banking emerges as a promising solution to address the challenges posed by these former mine lands. Not only does wetland banking restore idle land to productive use, but it also offers environmental benefits while serving the interests of property owners and local communities.

Initially conceived as a compensatory mitigation mechanism to uphold the wetland preservation requirements outlined in the 1972 Clean Water Act (CWA), wetland banking involves the restoration, creation, or enhancement of wetlands to offset potential development impacts on other wetlands. Over time, wetland banking has become a widely adopted compensatory mitigation approach, offering numerous advantages, particularly in the context of former mine lands.

The Army Corps of Engineers is responsible for overseeing the exchange of credits on a project-specific basis, determining the required number and availability of credits needed to offset proposed impacts in accordance with the terms outlined in the banking instrument. Upon approval from the Corps, the sale of credits is authorized, and the bank sponsor issues a certificate or receipt to the purchaser. Subsequently, the purchaser presents this certificate to the regulatory authority as proof of the completed transaction, thereby satisfying the developer's mitigation requirement.

Additionally, the bank sponsor is tasked with making appropriate real estate arrangements, such as establishing conservation easements and transferring title to a federal or state resource agency or non-profit organization. These measures ensure the preservation of the wetland in perpetuity, safeguarding continued wetland functioning at the site while prohibiting incompatible uses such as industrial development or vehicular use.

Wetbud, a freely available tool, offers a means to estimate wetland water budgets by utilizing accessible weather data along with site-specific geohydrologic, topographic, and soil data. It employs mass-balance calculations and was developed by an interdisciplinary team. Validated across various sites in Virginia using established and novel water budget techniques, Wetbud was initially designed as a planning tool for created wetland design. However, it can also be applied to native wetlands or wetland restoration sites with adequate data.

Wetbud operates in two primary forms: Basic and Advanced. The Basic version simplifies wetland topography, soil parameters, surface overland flow, and groundwater flux from adjacent hillsides. Conversely, the Advanced version incorporates these parameters in a more intricate approach utilizing a finite difference model (MODFLOW), enabling the inclusion of slopes or irregular topography in the model. Both versions allow for estimates of overbank flow from adjacent streams.

The program retrieves weather records from nearby stations, downloads user-selected data sets, and, after a minor data clean-up step, identifies appropriate wet-normal-dry (W-N-D) years for the station. For humid-temperate climate settings (e.g., Virginia to Missouri), Wetbud can employ Effective Monthly Recharge (Wem) calculations based on short-term groundwater data to simulate longer-term groundwater inputs for historical periods lacking well data, such as the selected W-N-D years.

Moreover, Wetbud offers a "Wizard" version equipped with 14 pre-selected weather data sets covering Virginia. This version allows users to develop a simple monthly water budget in under 15 minutes, a feature that could be expanded geographically with historic weather data availability.

This paper will present the basic concepts behind wetland design using Wetbud.

Towards Inclusive Territorial Governance in Mine Closure and Post-mining Economies

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Abstract

Mine closure processes pose substantial territorial governance challenges, especially in managing environmental and socioeconomic issues to ensure sustainable and just post-mining territories. These challenges are exacerbated by sudden closures, where existing plans often fail to mitigate the comprehensive impacts (Syahrir et al., 2021).

Recent literature reveals advances in the physical and ecological management of mine closures but highlights a persistent gap in integrating socioeconomic considerations (Vivoda et al., 2019; Marais et al., 2017; Wright et al., 2017).

Ineffective mine closure policies and failure to enforce regulation often overlook the importance of meaningful stakeholders' and rightsholders' engagement and consultation. This oversight leads to a lack of accountability among corporations and governments, restricts the potential for mining to contribute socio-economically, erodes community cohesion and obstructs the path toward equitable and inclusive governance (Coumans, 2019; Gregory, 2021).

This study underscores the critical role of territorial governance in facilitating a more just and enduring socioeconomic transition post-mining. It advocates for reformulating governance models to prioritize equitable development, integrating the rights and needs of local communities (Coumans, 2019; Christmann 2021; Dallabrida, 2015; Prno & Slocombe, 2012).

Aiming to strengthen mine closure processes, this research proposes an evaluation model of territorial governance that encompasses social, cultural, economic, and environmental dimensions, ensuring sustainability in post-mining periods.

Methodologically, this study presents a systematic literature review, analyzes international and Brazilian guidelines on mine closures, and incorporates expert validation of the proposed governance model. The proposed model offers a framework for engaging multiple stakeholders in developing inclusive and resilient development plans, marking a step forward in pursuing a just transition for mining territories.

References

Christmann, P. (2021). Mineral resource governance in the 21st century and a sustainable European Union. Mineral Economics. 34: 187-208.

Coumans, C. (2019). Minding the governance gaps: rethinking conceptualization of host state “weak governance and re-focussing on home state governance to prevent and remedy harm by multinational companies and their subsidiaries. The Extractive Industry and Society. 6: 675-687.

Dallabrida, V. R. (2015). Governança territorial: do debate teórico à avaliação da sua prática. Análise Social. 50(215): 304-328.

Gregory, H. G. (2021). Rendering mine closure governable and constraints to inclusive development in the Andean region. Resources Policy. 72: 102053.

Marais, L., van Rooyen, D., Nel, E. and Lenka, M. (2017). Responses to mine downscaling: Evidence from secondary cities in the South African Goldfields. The Extractive Industries and Society. 4(1): 163-171.

Prno, J. and Slocombe, D. S. (2012). Exploring the origins of ‘social license to operate’in the mining sector: Perspectives from governance and sustainability theories. Resources Policy. 37(3): 346-357.

Syahrir, R., Wall, F. and Diallo, P. (2021). Coping with sudden mine closure: The importance of resilient communities and good governance. The Extractive Industries and Society. 8(4): 101009.

Vivoda, V., Kemp, D. and Owen, J. (2019). Regulating the social aspects of mine closure in three Australian states. Journal of Energy & Natural Resources Law. 37(4): 405-424.

Wright, S. and Bice, S. (2017). Beyond social capital: A strategic action fields approach to social licence to operate. Resources Policy. 52: 284-295.

Life Cycle Assessment

Life Cycle Assessment as a Tool that Drives Decision to Manage and Lower the Environmental Impacts

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1. Introduction

Industrial minerals sector over the last 15 years has engaged extensively into the development of industry European average life cycle assessment studies using the ISO standards 14040-14044 and undergoing an external critical review.

These LCA studies delivered a multi-fold service: Toward the member companies to identify the hot spots of the different life cycle stages from cradle to gate of the mineral manufacturing companies. Resulted beneficial to be shared with the downstream users of these minerals to produce goods (such as steel, ceramics, cement, glass, etc) and deliver services (i.e. water purification, biocide, …) in various applications containing and/or needing these minerals. The wider use of minerals and the availability of LCA studies created learning opportunities with various value chain stakeholders towards innovation possibilities, environmental improvements and better exchange of information using standardised tools and documentation (such as Environmental Product Declarations (EPD’s).

As the information is reliable and has undergone external verification, it has also created more visibility to the versatility of mineral uses and has been shared with other stakeholders, such as policy makers; LCA consultants; university researchers, other interested stakeholders that are willing to exchange existing practices with more sustainable raw materials alternative such as minerals. The paper will illustrate examples of LCA as a decision-making tool by different stakeholders.

2. Methodology

Over the last years, the development of Life Cycle Inventory (LCI) and Life Cycle Assessment (LCA) studies has increased exponentially and the quality of the LCI/LCA studies improved. These developments are due to the developments of robust methodologies such as the early ISO standard 14040-14044 series that have been updated over the years (EN ISO 2006/2018, 2006/2020); the development of the International Life Cycle Database (ILCD) Handbooks by Joint Research Center (JRC) from the European Commission (EC) (2010a, 2010b) as well as the development of consistent templates such as the Environmental Product Declarations (EPD’s) on how to communicate down the value chain for specific applications, such as construction (EN 2012/2019, EN 2017/2022).

All the LCI/LCA studies use the same methodology consisting of 4 key steps:

1) Define the goal and scope
2) Develop the Life cycle inventory analysis,
3) Calculate the environmental impact assessment,
4) Interpretation of the results.

The boundaries of the LCI/LCA studies can vary depending on the agreed goal and scope (step 1). Typical system boundaries are: Cradle to gate; Cradle to use; Cradle to end of life as well as Cradle to cradle. LCI/LCA studies can be conducted at site level; product level; multiple sites; country/region level; corporate level or along the value chain.

An LCA study involves a thorough inventory of the input and output flows. On the side of inputs, the following are relevant: raw materials, energy, water, auxiliary products. On the output side: final products/services assessed; energy consumption, materials used, waste emissions to air, water and soil. The LCA will assess cumulative potential environmental impacts from multiple input/output flows. The aim of LCI/LCA studies is to map, identify hot spots and define action areas to improve the overall environmental profile of the product/service by serving as a holistic baseline upon which carbon footprints and other environmental impacts can be accurately compared.

These tools have demonstrated that if the boundaries are clearly defined and thanks to efforts to harmonize the methodologies and the tools, they can deliver reliable and consistent and transparent results to the users of these LCI/LCA studies. The ISO standards (EN ISO 2006/2018, 2006/2020) require an external verification which assesses the list of assumptions used to develop the study and the outcome of the LCI/LCA study. This step contributes to a higher level of accuracy and transparency.

As minerals are in the beginning of the value chain and they are used in a multitude of applications, this contribution will summarize the work done by Industrial Minerals Association Europe (IMAEurope) and its dedicated mineral associations to develop LCI studies for multiple mineral products from Cradle to Gate of the mineral producing plants. The transport of the minerals to the user is not included in the scope of the mineral sector studies due to the difference in transportation distances and different transportation modules (track, barges and/or trains).

3. Results

Over the last years, the development of LCA studies has increased and the quality of the LCA studies improved as well. Industrial Mineral Association Europe (IMA-Europe) member companies have committed to deliver reliable information on their operations and develop sector specific LCI studies from cradle (extraction) to gate (of the mineral operations). Following the ISO standard guidelines, the following are agreed in the Goal & scope phase of each study:

The refence unit: 1 ton of product

To meet the data quality requirements, the following data quality considerations are documented during the study:

1. Temporal coverage (a reference year is agreed for all the studies (Table 1).
2. Technological coverage (all studies are representative for the technology at the time of the study).
3. Geographical coverage (for each study members define the graphical representativeness of the study. Please refer to the specific study for the specific energy mix of each study. The energy mix used for the study is representative for the IMA member companies extracting and producing in the region Europe-27 + Norway + Turkey + UK + Ukraine).
4. List all literature and data sources used for the purpose of the study.
5. Uncertainty of information and any recognized data gaps are listed for each study. All these base data & assumptions are verified by the external verifier to increase the study transparency and wide dissemination of these results for the users of these minerals.

The LCI studies as they are finalized and updated regularly are made freely available in the GaBi platform (2024) and the EPD's in the Environdec platform (EPD Library, 2024). The findings from these studies have helped to identify the low impact of mineral extraction step, which generally is between 5-7% of the overall environmental impacts especially linked with the fuel used by the heavy machineries used for extraction. The highest impacts are related to the mineral processing steps. The more processing steps are used, the higher are the overall environmental impacts. The hot spots of mineral processing are:

1. Calcination
2. Drying and
3. Milling

These studies have helped members to look more into solutions on how to mitigate these impacts internally at site and or at corporate level.

Table1: List of LCI studies developed for minerals by IMA-Europe members.

LCI projects	Reference year	Products	No of products	Status for LCI studies	EPD's for construction
EuLA* LCI	2021	Quicklime Hydrated lime Dolime	3	2024 Update finalized	Quicklime Hydrated lime Dolime
CCA* LCI	2021	GCC** - dry course GCC - dry fine GCC - dry ultrafine GCC - slurry ultrafine PCC** - dry PCC - slurry	6	2021 Update finalized	GCC-dry course GCC-dry fine GCC-dry ultrafine
EuBA* LCI	2021	Bentonite - Unprocessed Bentonite - Sodium activated granular Bentonite - Sodium activated powder	3	2024 Update finalized	/
KPC* LCI	2017	Kaolin Coarse (Unprocessed) Kaolin Fine Kaolin Calcined Kaolin clay Shredded Kaolinitic clay processed	5	2021 Update Finalized	Kaolin Coarse (Unprocessed) Kaolin Fine Kaolin Calcined Kaolin Clay Shredded Kaolinitic Clay Processed
EuroFEL* LCI	2020	Feldspar - Floated & Dried Feldspar - Dry Milled	2	2022 LCI study finalized	/

**EuLA- European Lime Association; CCA-Calcium Carbonate Association; EuBA-European Bentonite Association; KPCKaolin & Plastic Clay Association; EuroFEL-European Feldspar.*

***GCC-Ground Calcium Carbonate; PCC-Precipitated Calcium Carbonate.*

4. Conclusions

These LCI/EPD studies have provided valuable information for various value chain actors and serve as a good basis for action, engagement, and inspiration. Can be summarized that, the LCI studies help the:

- Mineral producers: To identify hot spots and develop projects to reduce the impact of these hot spots within the mineral operations.
- Users of minerals: Understand, discuss and engage within the value chain how to lower the overall impacts at mineral level or at various life cycle stages or how to make savings by using mineral solutions for the specific end application.
- LCA practitioners: Over the last years, the number of LCA studies has increased and the quality of the LCA studies has improved. Over the last 15 years, more than five hundred requests have been satisfied from the IMA secretariat using the LCI studies reported above. The LCI/EPD data has been pivotal to respond with industry representative and qualitative data coming from these studies. This number will be even higher if company inquiries are added.
- Policy makers: To have a better understanding of the overall impacts of locally sourced minerals within EU using the EU Principles of Sustainable Raw Materials (European Commission, 2021) and compare with impacts of minerals produced outside of EU and the impact of transporting them over long distances in terms of cost and environmental footprint.
- Industry associations: Serve as inspiration to the IMA-Europe sister association in USA to develop similar projects for their US and EFTA members by refining the geography, energy mix, technology representatives accordingly.

5. References

EN 15804 (2012) + A2 (2019) Sustainability of construction works – Environmental Product Declarations (EPD) – Core rules for the product category of construction products.

EN 16908 (2017) + A1 (2022) Cement & building lime – Environmental Product Declaration (EPD) – Product Category Rules (PCR) complementary to EN15804.

EN ISO 14040 (2006) + EN ISO 14040: 2006/A1 2020: Environmental Management – Life Cycle Assessment – Principles and framework & Amendment 1.

EN ISO 14044 (2006) + EN ISO 14044: (2006)/A1 (2018) + EN ISO 14044: (2006)/A2 (2020): Environmental Management – Life Cycle Assessment – Requirements and guidelines Amendment 1 & Amendment 2.

EPD Library (2024). EPD International. Retrieved from: environdec.com

European Commission (2021). EU principles for sustainable raw materials - Publications Office of the EU.

GaBi Platform (2024). LCA Database - Sphera

JRC - European Commission, (2010a). International Life Cycle Database (ILCD) handbook, General guide for life Cycle Assessment – Detailed guidance.

JRC - European Commission, (2010b). International Life Cycle Database (ILCD) handbook, General Guide for Life Cycle Assessment – Specific Guide for Life Cycle Inventory datasets.

Unique and Comprehensive Approach to Raw Materials Education, Covering Life Cycle Assessment/Costing (LCA/LCC)

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Abstract

The European Union (EU) has committed under the EU Green Deal to become the first carbon-neutral continent by 2050 by introducing innovation and relevant education. For that purpose PhD level course program will focus on Life Cycle Assessment/Costing (LCA/LCC) and new business development, which are in high demand from EU industry partners. Emphasising converting the acquired knowledge into actionable entrepreneurship. This program will prepare the talents with innovative solutions/ideas to apply for entrepreneurship funding in other EIT activities, additionally the PhD student teams can validate their business idea via EIT Jumpstarter while also providing them with the necessary skills and knowledge in LCA/LCC and new business development.

Our goal is to support the EU's efforts to achieve its carbon-neutrality objective by enabling the next generation of green entrepreneurs to develop sustainable business practices. The uniqueness of the course lies with one of the biggest challenges for the industry and those who perform the LCA/LCC analysis which is the lack of understanding of a common “language” and methodologies and what information is required from the industry to perform proper LCA/LCC analysis to support the green transition.

To be successful, we have identified industrial associate partners and start-ups who are open and willing to be the source of real LCA/LCC case studies for the course to enable students to co-create feasible solutions through open innovation while supporting networking and matchmaking opportunities. This allows to prepare young professionals who are ready to communicate using language used by LCA and LCC experts and use their new knowledge to enhance sustainability at EU companies, as well as empower them to move their ideas from knowledge to application via new business development.

Life Cycle Inventory for Life Cycle Assessment: Interoperability Challenges, Opportunities and Tools

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1. Introduction

Life cycle inventories are central to any life cycle assessment (LCA) project. Ideally, these inventories must be interoperable across LCA modelling software platforms and databases since inventories (foreground and background) are obtained from different sources to quantify the resource use and emissions associated with each stage of a product's lifecycle (from cradle-to-gate, cradle-to-cradle, etc.). Life cycle inventory (LCI) found in databases, repositories, and modelling software often has unique format, structure, and quality.

This presents a fundamental problem and a modelling pain point within the LCA community, especially when porting LCI from one source to another, as extensive processing and elementary flow mapping must be undertaken to obtain LCI in a form suitable for modelling. This lack of interoperability poses a significant barrier to a more unified inventory integration from different sources, ultimately compromising the reliability and accuracy of LCA results. It is now well-established that data quality and interoperability are of major concern within the LCA community (Suh et al., 2016; Reap et al., 2008; and Ingwersen, 2015).

To address this challenge, the global LCA community has recognized the urgent need to establish common data exchange formats, metadata standards, and data quality guidelines geared toward promoting interoperability across modelling software platforms and databases. This effort aims to ensure that LCI is readily accessible, interoperable, and of high quality, thereby enabling more reliable LCA. This paper explores concepts and guidelines related to LCA data quality, and examines the current state of interoperability in LCI, highlighting challenges, opportunities, and existing tools. Additionally, we outline our strategy for harmonizing LCI formats through our ongoing development of an inter-database data conversion tool. Lastly, we emphasize the importance of collaborative efforts among LCA practitioners to promote interoperability standards and practices to enhance the reliability and accuracy of LCI for supporting rigorous LCA.

2. Methods

The current study discusses literature encompassing data quality and interoperability within the LCA community. It compiles and analyses tools used within the LCA community to harmonize LCI, including the mapping of elementary flows from source to target cantered around the Federal LCA Commons Elementary Flow List (FEDEFL). In the last part of this study, we have described the development of a novel web application (Mine Sustainability Modelling Group (MSMG) elementary flow formatter) to facilitate the harmonization of elementary flows from a source to a specified target across platforms and databases. We have validated the MSMG elementary flow formatter using inventory from the US EPA database.

3. Results and Discussion

3.1 General Observations on Data Quality

Several aspects of data quality within the context of LCA have been discussed in the prior work of Weidema and Wesnaes (1996), Edelen and Ingwersen (2018), Coulon et al. (1997), and Fava (1992). Collectively, these studies outline the criticality of data quality in LCA. Data quality describes the characteristics and attributes of LCI data that determine its ability to accurately and reliably represent the inputs, outputs, and environmental impacts associated with a product or process system under study.

Data quality management and assessment must be treated as an integral part of any LCA project from the onset. Weidema and Wesnaes (1996) note that the process of managing data quality commences with establishing clear "data quality goals" that capture the overall characteristics of the data. They suggest a series of data quality indicators (DQI) that a practitioner can use as metrics or measures to quantify the quality of data with respect to the goals. Fava (1992) and Coulon et al. (1997) grouped these metrics into quantitative (e.g. completeness) and qualitative (e.g. consistency and identification of anomalies).

An innovative approach to complement DQI could be the recently modified pedigree matrix (US EPA pedigree matrix) that defines data quality at both the flow and process level (Edelen and Ingwersen 2018). It should be noted that even though the modified pedigree matrix provides a high level of clarity, this strategy has not been designed to overcome all the challenges of data quality. An approach to comprehensive data quality assessment and management could involve the inclusion of expert judgment, peer review of data, and due diligence. This can help enhance the quality of data used in an LCA project and provide more informed assessments of DQIs at both the flow and process levels.

However, LCA practitioners often encounter challenges with completeness, consistency, and data anomalies when obtaining LCI from different sources to tailor it to the specific needs of a project. This lack of interoperability poses a significant barrier to the integration of LCI across platforms. One of the most prevalent challenges in achieving interoperability is the inconsistency or mismatch of elementary flows across different life cycle assessment modelling platforms.

In recent years, however, interoperability challenges have been recognized by the LCA community and an action plan to establish common data exchange formats, metadata standards, and data quality reporting guidelines across modelling software platforms has been launched (Table 1). These efforts range from national (e.g. U.S. EPA, see Edelen et al., 2019) to global initiatives (e.g. Global Life Cycle Assessment Data Access (GLAD) initiative, see Valente et al., 2024).

Table 1. Notable tools for LCI interoperability

Tool/Project	Reference	Repository/Source
GLAD Mapper	Valente et al. (2024)	https://github.com/UNEP-Economy-Division/GLAD-ElementaryFlowResources
Federal LCA Elementary Flow List (FEDEFL)	Edelen et al. (2022)	https://github.com/USEPA/fedelemflowlist
EPA / USDA LCA Harmonization Tool (LCA-HT)	Ingwersen and Ciroth (2015)	https://github.com/USEPA/LCA-HT
openLCA format converter	Ciroth et al.(2013)	https://www.openlca.org/format-converter/
LCIA Formatter	Young et al. (2021)	https://github.com/USEPA/fedelemflowlist
MSGM Elementary Flow Formatter	This study	Ongoing work

The LCIA Formatter package, developed by Young et al. (2021), comprises modules designed to format elementary flows using the Python programming language. This approach was complemented by data extraction from various methods or sources such as TRACI2.1 (Bare, 2011), ReCiPe2016 (Goedkoop et al., 2009), and ImpactWorld+ (Bulle et al., 2019), which were then mapped to the United States Environmental Protection Agency (USEPA) ecosystem, such as the Federal LCA Commons Elementary Flow List (FEDEFL) (Edelen et al., 2019), for integration into software such as openLCA. However, users of this package must possess proficiency in the Python programming language, which could pose a challenge for LCA practitioners lacking programming skills. The Mine Sustainability Modelling Group (MSMG) Elementary Flow Formatter addresses this challenge with dual objectives: 1) providing a more accessible and user-friendly platform (via a web application) to harmonize elementary flows that can be used by LCA practitioners without programming backgrounds; and 2) enabling LCA practitioners to conduct modelling in their preferred software without the need for additional processing.

3.2 MSMG elementary flow formatter architecture

The web application is developed in the R programming language (R Core Team, 2024) using the Shiny package (Chang et al., 2024). The platform consists of three main features (Figures 1 and 2). The core feature is the user interface (frontend) and server (backend) designed to accept input data in CSV (Comma delimited) format, automatically process this input data, and make the results accessible in a format consistent and ready to be used in an LCA modelling software. The server side of the software has been populated with the FEDEFL, making it easier to map the elementary flow across methods (e.g. ReCiPe) and process-specific elementary flow (e.g. cement manufacturing industry). Within the context of this web application, process flow denotes elementary flows obtained from sources such as the Greenhouse Gas Reporting Program (GHGRP), National Emissions Inventory (NEI), Discharge Monitoring Reports (DMR), Toxic Release Inventory (TRI), etc., from the EPA databases for a particular industrial sector (see e.g. Hottle et al., 2022 and Cashman et al., 2016).

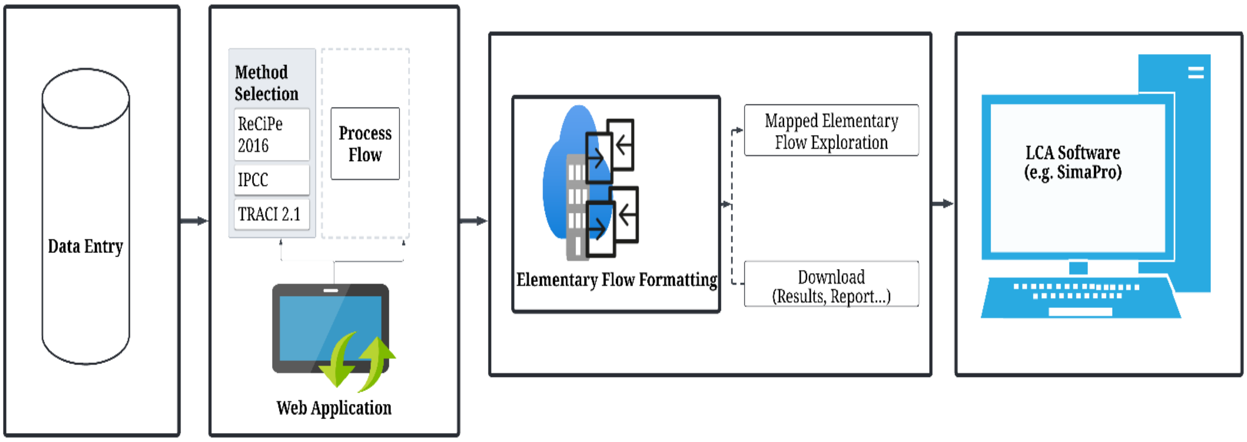
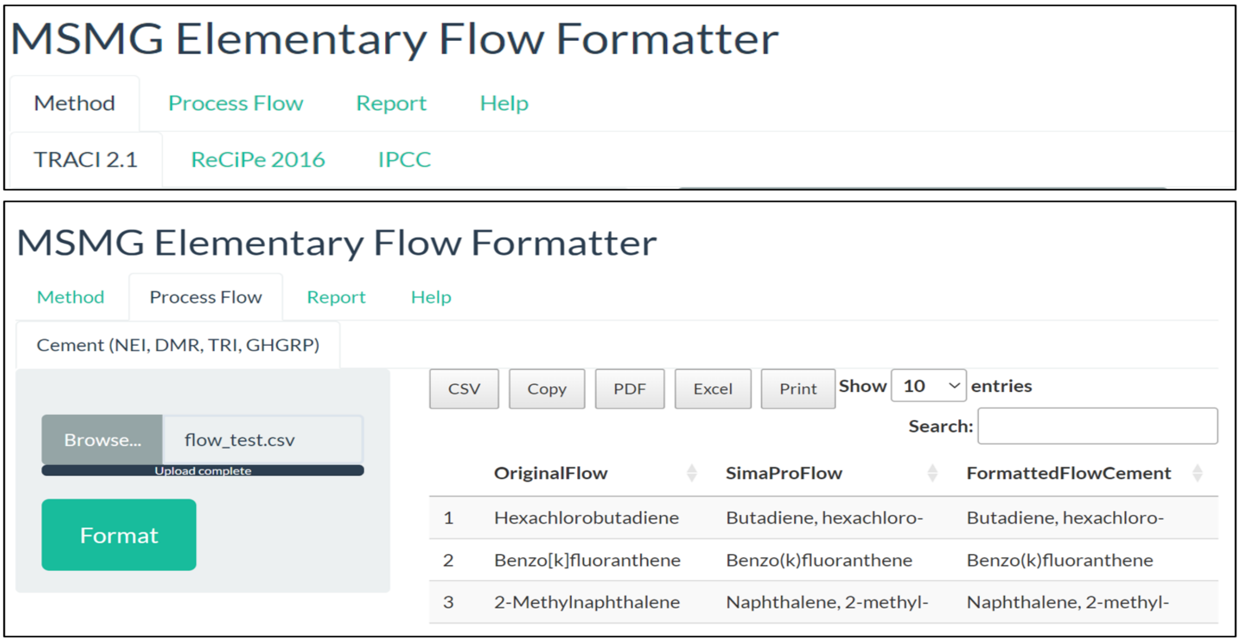


Figure 1. Features of the MSMG elementary flow formatter and workflow



	OriginalFlow	SimaProFlow	FormattedFlowCement
1	Hexachlorobutadiene	Butadiene, hexachloro-	Butadiene, hexachloro-
2	Benzo[k]fluoranthene	Benzo(k)fluoranthene	Benzo(k)fluoranthene
3	2-Methylnaphthalene	Naphthalene, 2-methyl-	Naphthalene, 2-methyl-

Figure 2. User interface(frontend) of the MSMG elementary flow formatter

4. Conclusions and Outlook

This study set out to review data quality and interoperability challenges as well as opportunities for improvement and tools within the LCA community. The main finding is that further work needs to be undertaken regarding data quality and interoperability. While the global LCA community is actively working to facilitate the interoperability and accessibility of LCI, another possible area for future endeavors would be to bring all commercial and open-source LCA software, methods, and data providers under one umbrella to adopt a single data exchange format and elementary flow mapping tool. Such a collaborative effort could be a reasonable approach to tackling the issues of data quality and interoperability.

Our current work on the MSMG Elementary Flow Formatter lays the groundwork for the future addition of more LCA methods and process-specific (across industrial sectors) elementary flows to the platform.

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6. References

Bare, J. (2011). TRACI 2.0: The tool for the reduction and assessment of chemical and other environmental impacts 2.0. Clean Technologies and Environmental Policy. 13(5): 687–696.

Bulle, C., Margni, M., Patouillard, L., Boulay, A.-M., Bourgault, G., De Bruille, V., Cao, V., Hauschild, M., Henderson, A. and Humbert, S. (2019). IMPACT world+: A globally regionalized life cycle impact assessment method. The International Journal of Life Cycle Assessment, 24(9), 1653–1674.

Cashman, S.A., Meyer, D.E., Edelen, A.N., Ingwersen, W.W., Abraham, J.P., Barrett, W.M. and Smith, R.L. (2016). Mining available data from the United States Environmental Protection Agency to support rapid life cycle inventory modeling of chemical manufacturing. Environmental Science & Technology. 50(17): 9013-9025.

Chang, W., Cheng, J., Allaire, J., Sievert, C., Schloerke, B., Xie, Y., Allen, J., McPherson, J., Dipert, A. and Borges, B. (2024). Shiny: Web Application Framework for R. R package version 1.8.1.1. Retrieved from: https://CRAN.R-project.org/package=shiny

Ciroth, A., Graf, I. and Srocka, M. (2013). The openLCA format converter – new release May 2013. Retrieved from: https://www.openlca.org/wp-content/uploads/2015/11/The-format-converter_May2013.pdf

Coulon, R., Camobreco, V., Teulon, H. and Besnainou, J. (1997). Data quality and uncertainty in LCI. The International Journal of Life Cycle Assessment. 2(3): 178–182.

Edelen, A. and Ingwersen, W.W. (2018). The creation, management, and use of data quality information for life cycle assessment. The International Journal of Life Cycle Assessment. 23: 759–772.

Edelen, A., Hottle, T., Cashman, S. and Ingwersen, W.W. (2019). The federal LCA commons elementary flow list: Background, approach, description and recommendations for use (No. EPA/600/R-19/092). U.S. Environmental Protection Agency.

Edelen, A. N., Cashman, S., Young, B. and Ingwersen, W. W. (2022). Life Cycle Data Interoperability Improvements through Implementation of the Federal LCA Commons Elementary Flow List. Applied Sciences. 12(19): 9687.

Fava, J., Jensen, A.A., Lindfors, L., Pomper, S., de Smet, B., Warren, J. and Vigon, B. (1994). Life-cycle assessment data quality: a conceptual framework. Report of a workshop held in October 1992, Wintergreen, SETAC Foundation for Environmental Education, Pensacola.

Goedkoop, M., Heijungs, R., Huijbregts, M.A.J., Schryver, A. D., Struijs, J. and van Zelm, R. (2009). ReCiPe 2008: A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level; report 1: characterisation (p. 132). Ministry of Housing, Spatial Planning, & Environment (VROM).

Hottle, T., Hawkins, T.R., Chiquelin, C., Lange, B., Young, B., Sun, P., Elgowainy, A. and Wang, M. (2022). Environmental life-cycle assessment of concrete produced in the United States. Journal of Cleaner Production. 363: 131834.

Ingwersen, W.W. (2015). Test of US federal life cycle inventory data interoperability. Journal of Cleaner Production. 101: 118-121.

Ingwersen, W.W. and Ciroth, A. (2015). Elementary Flow Harmonization with openLCA and the LCA Harmonization Tool. In the proceedings of the 4th Meeting of the International Forum on LCA cooperation, Shah Alam, Malaysia.

R Core Team. (2024). R: A language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing. Retrieved from: https://www.R-project.org

Reap, J., Roman, F., Duncan, S. and Bras, B. (2008). A survey of unresolved problems in life cycle assessment. The International Journal of Life Cycle Assessment. 13: 374–388.

Suh, S., Leighton, M., Tomar, S. and Kneifel, J. (2016). Interoperability between ecoinvent ver. 3 and US LCI database: a case study. The International Journal of Life Cycle Assessment. 21: 1290–1298.

Valente, A., Vadenbo, C., Fazio, S., Rabeau, M., Ingwersen, W.W., Edelen, A., Cashman, S., Srocka, M., Suh, S. and Hellweg, S. (2024). Elementary flow mapping across life cycle inventory data systems: A case study for data interoperability under the Global Life Cycle Assessment Data Access (GLAD) initiative. The International Journal of Life Cycle Assessment. 29: 789–802.

Weidema, B. and Wesnaes, M. (1996). Data quality management for life cycle inventories—an example for using data quality indicators. Journal of Cleaner Production. 4(3–4): 167–174.

Young, B., Srocka, M., Ingwersen, W.W., Morelli, B., Cashman, S. and Henderson, A. (2021). LCIA Formatter. Journal of Open Source Software. 6(66): 3392.

Towards a more Sustainable Supply of Critical Raw Materials: The Role of Prospective Life Cycle Assessment

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1. Introduction

Meeting the European Union's (EU) decarbonization targets will require an intensive consumption of critical raw materials (CRMs) (European Commission, 2018). Therefore, to ensure a more secure and sustainable supply, the European Commission recently adopted the Critical Raw Materials Act (European Commission, 2023). This regulation defines benchmarks for the domestic extraction, processing, and recycling of these essential minerals, thus drawing attention to previously unexploited resources. Such resources comprise unexploited low-grade primary deposits, as well as secondary waste streams (e.g., tailings), which will be crucial to reducing the EU's reliance on imports from third countries while achieving its decarbonization targets.

Despite the evident benefits from a resource conservation perspective, the production of CRMs from low-grade unexploited primary deposits and their recovery from waste flows might not always be environmentally preferable, due to, e.g., higher energy requirements, lower processing efficiency, higher emissions (Di Maria et al., 2024). Consequently, it is essential to conduct predictive (ex-ante) environmental assessments of these emerging production routes, as they can offer valuable insights to guide their development towards a sustainable direction.

The so-called Prospective Life Cycle Assessment (pLCA) methodology is a valuable tool for assessing the potential environmental impacts of emerging technologies before their widespread implementation (Arvidsson et al., 2018), and it can be potentially applied to emerging metal production routes. Here, we investigate how this methodology could be applied to novel processes with a high Technology Readiness Level (TRL), but not yet applied by industry, designed to produce and recover metals from unexploited resources. This work is part of the pLCAs of the processes developed within the Horizon Europe METALLICO project (https://metallico-project.eu/).

2. Materials and Methods

A Prospective Life Cycle Assessment is an environmental LCA that studies technology at an early phase of development (Arvidsson et al., 2018). Its main objective is not to provide an exact assessment of the environmental impacts of such emerging technology, but rather, to predict potential environmental hotspots and identify the most sustainable design choices. Its results can provide valuable information to steer process development towards a more sustainable direction.

Unlike a traditional LCA, which assesses established industrial processes, a pLCA analyzes a technology that is only developed at small scale (low TRL). However, its final goal is not to evaluate the potential environmental impacts of such emerging technology at lab or pilot scale, but to project this assessment to a potential future industrial scale. This presents multiple challenges (Table 1), as the temporal and scale perspectives between the level of development of the emerging technology (currently at lab or pilot scale) and the intended scope of the assessment (future industrial scale) differ significantly. More specifically, assessing a potential future development pathway of an emerging technology requires starting from small-scale data and subsequently scaling them up to an industrial level, while accounting for potential evolutions of both the foreground system (i.e., the processes that can be changed or directly influenced, such as materials input ratios or process efficiencies) and the background system (i.e. the processes that cannot be directly influenced, for instance, the future energy mix of a country).

Given the inherent challenges of pLCA, a literature review was conducted to investigate the use and the applicability of this methodology within the mining sector. The initial selection involved using keywords such as: "prospective LCA", "ex-ante LCA", and "anticipatory LCA". After that, only case studies targeting innovative processes for the extraction of metals from unexploited primary deposits or for their recovery from waste flows were selected for further analysis. Additionally, review papers were screened to gain a broader understanding of recommended approaches for conducting pLCAs. The main objective was to identify the most common methodological approaches, as well as to gather recommendations for conducting pLCAs in the mining sector and to understand potential environmental challenges associated with future emerging metals' production routes.

3. Results and Discussion

Due to its relatively recent introduction, the adoption of pLCA within the mining sector remains limited. Therefore, this analysis was constrained to a small number of case studies. Nevertheless, from the selected case studies, it was still possible to derive some useful recommendations for adopting the pLCA in the mining sector. Furthermore, these studies helped identify potential future environmental challenges associated with emerging metals’ production routes.

Table 1 highlights the main difficulties encountered when performing a pLCA and outlines the principal methodological strategies employed to address them in the selected case studies. In general, the data collected at small scale have been upscaled to future industrial levels with a simplified approach based on a combination of scaling relationships and approximations with proxies derived from the literature. Despite its simplicity, as highlighted by Buyle et al. (2021), employing such an approach for processes at low TRL can be as effective as conducting complex process simulations, yielding similar results. Furthermore, recognizing the uncertainty inherent in this scaling approach, different scenarios have been explored in sensitivity analysis to understand how different process yields, material input ratios, or energy mixes could affect the results. However, only a limited number of case studies have additionally considered the evolution of the background system within these scenarios.

Beyond methodological recommendations, the analysis of the selected case studies allowed deducting more general considerations on emerging metals’ production routes. An important observation is that despite benefits from a resource conservation perspective, the production of metals from new primary sources or waste streams may not always yield environmental benefits when compared to current production routes. Trade-offs are likely, as demonstrated by tailings valorization processes, where, despite higher climate change impacts, reductions in toxicity-related impacts can be achieved (Fig 1).

Figure 1 summarizes the results of three different pLCAs of emerging tailings valorization processes. For each single process, the highest impact within each indicator is set to 100%, while the other is expressed as a percentage of it. The bars on the right side of the graph represent the impacts related to the materials and energy used in the processes, while the left bars illustrate the advantages derived from avoiding tailings disposal and avoiding the primary productions of the recovered materials.

Table 1. Methodological challenges of pLCA and most adopted solutions in the selected case studies

Methodological challenges	Explanation	Most common approaches
Inventory data upscaling	Data are collected at lab or pilot scale, but the technology is modelled at a potential future industrial phase	Data are upscaled to industrial levels through the combination of engineering-based scaling relationships, approximations based on literature information (proxies), and the opinions of experts
Scenario development	The potential future evolution of the emerging technology is unknown and thus multiple potential development trajectories should be explored	Scenarios focused more on different process evolutions (e.g., different material inputs, processes efficiencies, or configurations) rather than considering the evolution of potential external factors (e.g., future electricity grid mixes)
Background system evolution	The background data should represent the future environment in which emerging technologies are expected to become commercially operational	Future evolution is generally not considered. When done, it is limited only to future electricity mixes
System expansion	Approach adopted in waste valorization processes to account for the credits resulting from the avoided primary production of the recovered materials	The recovered materials are assumed to perfectly substitute virgin ones (substitution ratio 1:1). Different substitution ratios are sometimes explored in sensitivity analysis

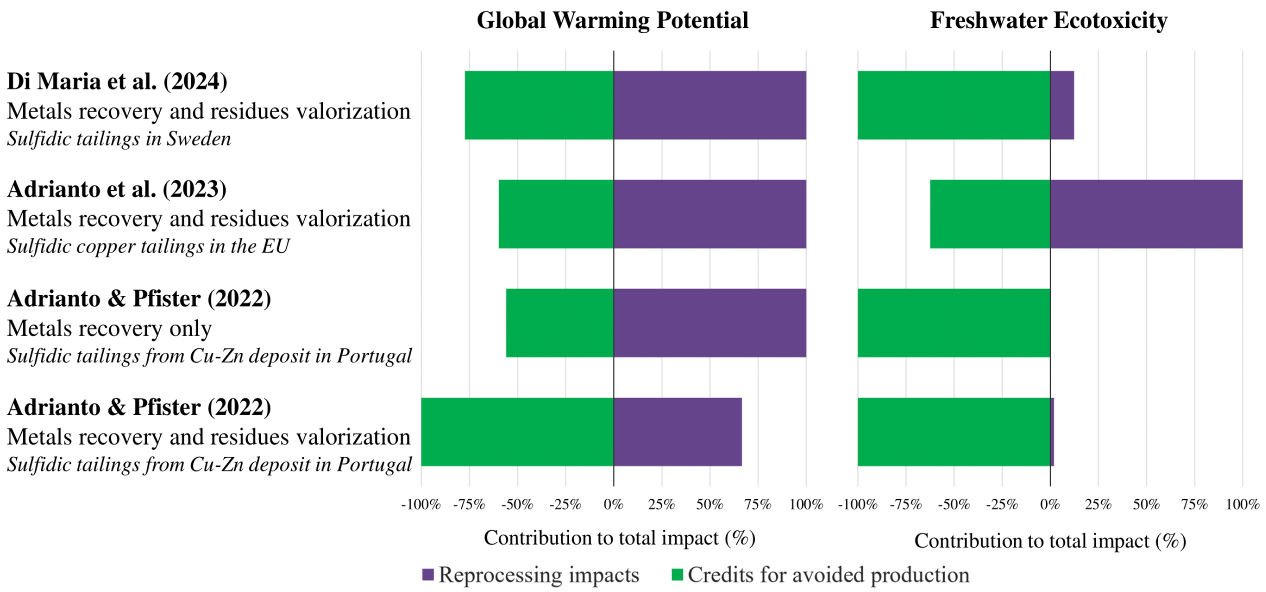

Figure 1. pLCAs results for different tailings valorization processes. Wider left bars indicate that the environmental benefits from avoiding primary production outweigh the impacts associated with the tailings valorization processes

As it can be observed, in general, the reprocessing impacts (direct emissions and impacts related to the materials and energy used) outweigh the benefits resulting from the avoided primary production of the recovered materials for the Global Warming Potential (GWP) impact category. This is due to the high direct emissions and energy requirements of the processes themselves. By contrast, the recovery of metals enables significant reductions of Freshwater Ecotoxicity impacts by avoiding acid mine drainage, thus making these processes environmentally beneficial from this point of view. However, it's essential to emphasize that the greatest environmental advantages are obtained when metal recovery is coupled with the valorization of mineral residues (see results by Adrianto and Pfister, 2022) for metals recovery only and metals recovery and residues valorization). Therefore, emerging tailing processes should not only prioritize critical metal recovery but also strive to optimize their circularity.

4. Conclusions

A systematic review of the literature on prospective LCAs in the mining sector was conducted for emerging metals' production routes from primary resources and waste streams. Although preliminary, the current state of research can help derive recommendations to support the application of pLCA in this specific sector, on crucial aspects of pLCA, such as data scale-up and scenario development. Moreover, potential future environmental challenges associated with emerging metals' production routes were identified. This information will be used to guide the pLCAs of the processes developed within the Horizon Europe METALLICO project.

5. Acknowledgements

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6. References

Adrianto, L.R., Ciacci, L., Pfister, S. and Hellweg, S. (2023). Toward sustainable reprocessing and valorization of sulfidic copper tailings: Scenarios and prospective LCA. Science of The Total Environment. 871: 162038.

Adrianto, L.R. And Pfister, S. (2022). Prospective environmental assessment of reprocessing and valorization alternatives for sulfidic copper tailings. Resources, Conservation and Recycling. 186: 106567.

Arvidsson, R., Tillman, A., Sandén, B.A., Janssen, M., Nordelöf, A., Kushnir, D. and Molander, S. (2018). Environmental Assessment of Emerging Technologies: Recommendations for Prospective LCA. Journal of Industrial Ecology. 22(6): 1286–1294.

Buyle, M., Maes, B., Van Passel, S., Boonen, K., Vercalsteren, A. and Audenaert, A. (2021). Ex-ante LCA of emerging carbon steel slag treatment technologies: Fast forwarding lab observations to industrial-scale production. Journal of Cleaner Production. 313: 127921.

Di Maria, A., Khoshkhoo, M., Sand, A. and Van Acker, K. (2024). Towards sustainable resource valorization: A life cycle sustainability assessment of metals recovery from sulfidic mining residues in Sweden. Resources, Conservation and Recycling. 204: 107513.

European Commission. Directorate General for Internal Market, Industry, Entrepreneurship and SMEs. (2018). Report on critical raw materials and the circular economy. Publications Office. Retrieved from: https://data.europa.eu/doi/10.2873/167813

European Commission. (2023). European Critical Raw Materials Act. European Commission.

The Role of Social Life Cycle Assessment (S-LCA) towards more Sustainable Mining. Methodology and Metrics from the Horizon Europe Mine.io Project

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1. Introduction

The mining sector is essential to provide raw materials and inputs for all sectors, which are crucial to support the population's well-being and enabling the performance of economies (Mancini & Sala, 2018). On the other hand, mining activities can generate social and environmental impacts, affecting e.g., local communities, workers, society as a whole (Raderschall & Springare, 2019). The Horizon Europe Mine.io project (https://mineio-horizon.eu/) aims to enhance the overall sustainability of the mining sector through the introduction of new technologies and a novel mining digital ecosystem. Within this framework, this work focuses on developing a methodology to assess the social consequences associated with mining activities in general and with Mine.io innovations specifically.

The methodology considers the currently available literature and guidelines on social impacts assessment, with a specific focus on methodologies applied to the mining sector. Literature in this field is not particularly abundant, but neither scarce. Growing interest and efforts in the scientific community is connected to the methodology of Social Life Cycle Assessment (S-LCA), which has a structure aligned with the Environmental LCA, but where the focus are social aspects occurring along the life cycle of a product. S-LCA is not yet standardized, but recent guidelines have been developed by UNEP-SETAC (Benoît Norris et al., 2020). Studies developed following this methodology are available also in the mining sector (Di Maria et al., 2024; Di Noi & Ciroth, 2018; Mancini et al., 2018).

Parallelly, complementary approaches have been developed also in other fields, such as the chemical sector. For example, in a report of the European Commission on chemicals and materials, a reference scale assessment method is used, enriched, when possible, by company data (Caldeira et al., 2022). A very recent publication is the standard GRI 14 (Global Sustainability Standards Board (GSSB), 2024), aiming at enabling organizations to report information about their most significant impacts on the economy, environment, and people, including impacts on their human rights, and how it manages these impacts. The GRI 14 is specifically developed for the mining sector and analyses 24 different material topics, related to the environment, local communities, workers, financial transparency and cross-cutting. The methodology proposed in this paper mainly builds on the literature mentioned and applies it to the specific goals of the Mine.io project.

2. Materials and Methods

The methodology developed in this study is summarized in the diagram of Fig. 1. The approach developed to assess the social aspects of mining activities, particularly within the pilot studies involved in the Mine.io project, begins with the identification of stakeholders to be considered. Stakeholders are individuals or groups with an interest in any activities or decisions of an organization. The main stakeholders' categories recommended by the UNEP guidelines (Benoît

Norris et al., 2020) are the following: workers, local communities, value chain actors (excluding consumers), consumers, society, and children. However, other groups of stakeholders may also be considered depending on the specific study.

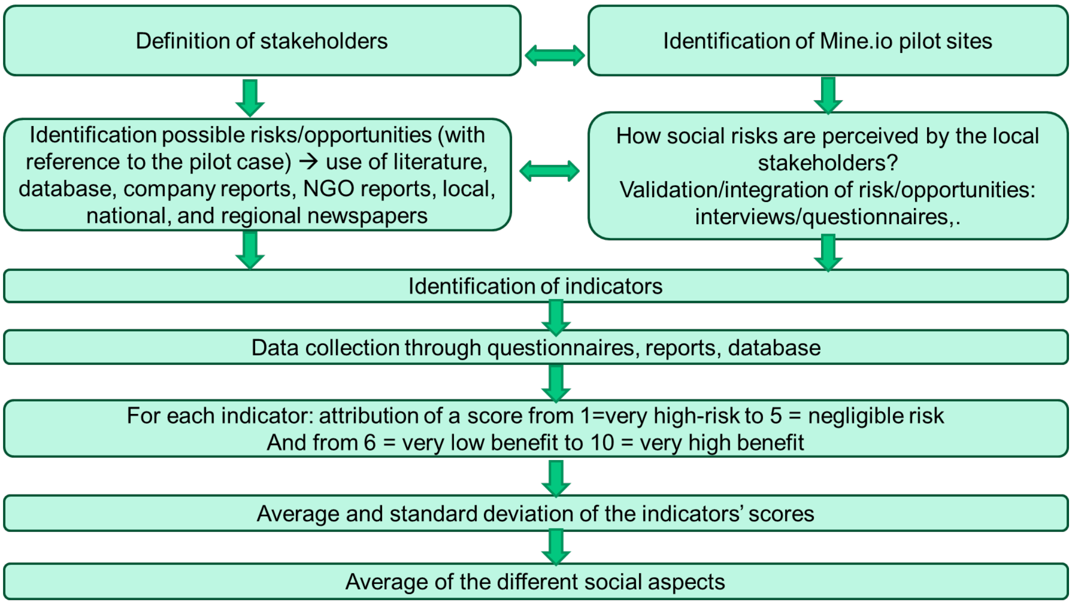
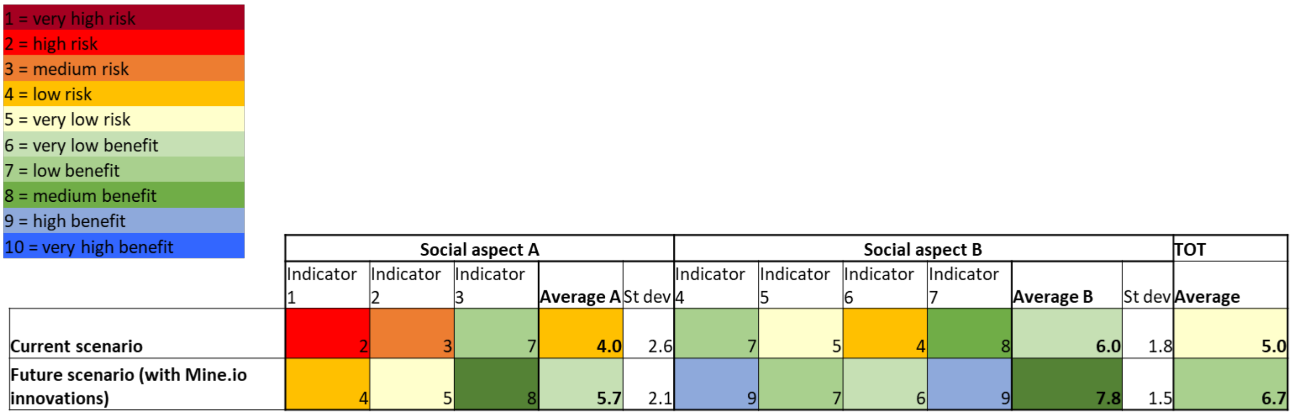


Figure 1. Diagram of the methodology developed for the social assessment in Mine.io project.

The selection of stakeholders parallels the identification of pilot sites, which is used to apply and test the methodology. Since the pilot sites of the Mine.io project differ significantly in terms of geography, type of extraction, and activity status, the affected people and the main social risks and benefits could vary accordingly. Key social aspects are identified through discussions with other partners of the Mine.io project, supplemented by information from literature, databases, companies and NGO reports, as well as local, regional and national newspapers. These social risks and benefits are validated and integrated through questionnaires to the local community on the perception of the social aspects related to the mine. For each different key social aspects, specific indicators are then defined to measure them. Subsequently, primary data (collected through questionnaires to the local community) and secondary data are employed to address the chosen indicators. This is done with reference to both the current scenario and the future scenario that will be achieved with the Mine.io innovations.


1 = very high risk
2 = high risk
3 = medium risk
4 = low risk
5 = very low risk
6 = very low benefit
7 = low benefit
8 = medium benefit
9 = high benefit
10 = very high benefit

	Social aspect A					Social aspect B						TOT
	Indicator 1	Indicator 2	Indicator 3	Average A	St dev	Indicator 4	Indicator 5	Indicator 6	Indicator 7	Average B	St dev	Average
Current scenario	2	3	7	**4.0**	2.6	7	5	4	8	**6.0**	1.8	**5.0**
Future scenario (with Mine.io innovations)	4	5	8	**5.7**	2.1	9	7	6	9	**7.8**	1.5	**6.7**

Figure 2. Example of assessment through the reference scale indicated on the top left of the figure.

The assessment is conducted using a reference scale ranging from 1 to 5 for risks, where 1 represents a very high risk and 5 represents a negligible risk, and from 6 to 10 for benefits, where 6 indicates a very low benefit and 10 indicates a very high benefit. Each indicator of every social aspect is evaluated using this scale, as illustrated in the example shown in Fig. 2. Subsequently, an average score and the corresponding standard deviation are calculated for each social aspect. The final score is derived as the average of the scores obtained for the various social aspects.

This methodology allows for the identification of the most critical social risks and significant benefits. Moreover, it facilitates the assessment of the magnitude of risks and benefits associated with the Mine.io innovations. The standard deviation provides insight into the degree of variability among the scores, indicating the consistency or dispersion of the assessments.

3. Results and Discussion

The described methodology is being applied to the Mine.io project. The selected stakeholders are the local community and the workers. Five pilot sites have been identified as case studies to test the methodology, which are:

- A copper and silver underground mine and surface processing plant located in Polkovice (Poland). The Mine.io innovation is focused on an enhanced flotation method.
- A polluted soil in Lavrion (Greece) where metal extraction (pb, cd, cu, as, zn) is investigated. This area is used for research and the Mine.io innovation is related to the use of technologies (magnetometer, drones, 3D modelling) to recover the metals.
- Zinc, copper and pyrite open pits located in Pyhäjärvi (Finland). The Mine.io innovation concerns the technologies (Multi-Source Data Fusion and Interpretation) for surveillance of tailings dams.
- A fluorspar underground mine and surface processing plant located in Niederschlag (Germany). The main focus of the Mine.io project is the electrification of the vehicles.

A Biotitic-orthogneiss open pit in Santa Maria de Feira (Portugal). The Mine.io project is focused on underwater technologies. It has to be underlined that the stakeholder “workers” is not suitable for the Lavrion pilot site since this latter is currently not active and only used for research. Also, some indicators related to the “local community” may not be applicable for the same reason.

The indicators selected to represent the potential social risks and benefits on the local community are here described. Two social aspects have been selected: the local economy and the socioeconomic, cultural and health impacts, aligning with the GRI 14 standard. The local economy is considered a key aspect in the social assessment of the mining sector, encompassing both risks and benefits on the local community. Therefore, the mining activity may lead to investments and incomes for the local community (expressed locally through procurement spending, capacity building, or employment provision, and at national, subnational, or regional levels through taxes and royalties). Employment impacts of mining may depend on how already existing jobs in other sectors are affected. In addition, the Mine.io innovative technologies could introduce new skills and increase work opportunities but could also reduce the number of workers employed in mining activities. Identified indicators for the local economy aspect include direct economic value generated and distributed; infrastructure investments and services supported; enhanced local skills and knowledge; number of jobs supported.

Mining activities could also pose risks related to the socioeconomic, cultural and health impacts, which could be eventually reduced by innovations introduced through the Mine.io project. Negative impacts may arise from land use requirements that limit availability of land and natural resources, leading to the loss of traditional culture or cultural identity. Additionally, mining activities may result in damage to tangible and intangible cultural heritage. Health and safety risks to the local community could stem from exposure to pollution, water contamination, increased traffic, noise pollution, reduced fishing and agricultural yields, and critical incidents. Potential indicators for assessing these aspects include area of land converted/resettled; volume and type of hazardous substances used/removed; volume and type of pollution released/removed, intensity of the impact/benefit; duration of the impact/benefit; reversibility of the impact; scale of the impact/benefit.

Questionnaires will be developed to assess how local communities perceive these social risks and benefits, and they will be translated into the official language of the country where the pilot site is located. The same approach will be applied with the stakeholder “workers”. This communication with individuals will enable a more meaningful and context-specific social assessment. Following the methodology described in the previous section, the evaluation will be conducted to assess the key social aspects associated with Mine.io mining activities and the related introduced innovations.

4. Conclusions

This paper presents a methodology for conducting social assessments within the context of mining activities, with a specific focus on the ongoing Mine.io project. The outlined methodology follows an iterative approach, whereby key social aspects relevant to the particular case study are identified through a combination of literature review and input from stakeholders in the field. Local communities and workers are identified as the main groups affected, either positively or negatively, by the mining site. Various indicators will be examined, and the assessment will be carried out using a reference scale methodology. This approach allows for the identification of primary risks and benefits, as well as the social implications associated with the innovations introduced in the mine. The methodology will be further refined and validated through the collection of primary data within the Mine.io project.

5. Acknowledgements

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6. References

Benoît Norris, C., Traverso, M., Neugebauer, S., Ekener, E., Schaubroeck, T., Russo Garrido, S., Berger, M., Valdivia, S., Lahmann, A., Finkbeiner, M. and Arcese, G. (2020). Guidelines for Social Life Cycle Assessment of Products and Organizations 2020.

Caldeira, C., Farcal, L.R., Garmendia Aguirre, I., Mancini, L., Tosches, D., Amelio, A., Rasmussen, K., Rauscher, H., Riego Sintes, J. and Sala, S. (2022). Safe and sustainable by design chemicals and materials. Framework for the definition of criteria and evaluation procedure for chemicals and materials. Publications Office of the European Union.

Di Maria, A., Di Noi, C., Román Escobar, Y., Vázquez Ruiz, A. and Ciroth, A. (2024). Synergies and challenges of bottom-up and top-down approaches for assessing social impacts in mining operation. The International Journal of Life Cycle Assessment. 29: 1075-1095.

Di Noi, C., and Ciroth, A. (2018). Environmental and social pressures in mining. Results from a sustainability hotspots screening. Resources, 7(4): 80.

Global Sustainability Standards Board (2024). GRI 14: Mining Sector 2024.

Mancini, L., Eynard, U., Eisfeldt, F., Ciroth, A., Blengini, G.A. and Pennington, D. (2018). Social assessment of raw materials supply chains. A Life-Cycle-Based Analysis. Luxemburg.

Mancini, L. and Sala, S. (2018). Social impact assessment in the mining sector: Review and comparison of indicators frameworks. Resources Policy. 57: 98–111.

Raderschall, L. and Springare, L.-S. (2019). Enhancing WELL-BEING in mining regions: key issues and lessons for developing indicators.

Key Challenges of Mining Life Cycle Assessments

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1. Introduction

The mining industry has been slow in adopting life cycle assessment (LCA) in decision-making, which may have slowed the development of LCA methods specifically for the mining and metals sector. However, there is an increasing trend by policymakers and the industry to use LCA to evaluate the sustainability of supply chains to inform investment, policy, and research decisions. Yet, even as stakeholders increasingly use LCAs for decisions about mining and metals supply chain, methodological issues persist. This work sought to evaluate current trends in mining LCA studies with particular attention paid to the challenges with mining and metals supply chains.

2. Methods

The work conducted a thorough review of the literature using major abstracting indices including Scopus and Google Scholar. The authors used keywords such as {life AND cycle AND assessment AND mining} OR {life AND cycle AND assessment AND metals} to retrieve papers. They then reviewed the resulting papers for relevance. They reviewed the final set of papers to determine trends and identify the issues. The evaluation identified three main challenges that this work focuses on:

1. data quality and gaps,
2. challenges with land use characterization, and
3. allocation issues.

To be clear, these issues are not the only issues plaguing mining LCA studies but the issues that the authors are most qualified to discuss in detail and provide sound recommendations based on their own previous research experience.

3. Results and Discussion

As shown in Figure 1, the number of papers archived in Scopus (searching with {life AND cycle AND assessment AND mining} OR {life AND cycle AND assessment AND metals} in "article title, abstract, keywords") has increased from 31 each for 2000 and 2001 to 475 in 2022. This >15fold increase is remarkable, even if one considers the general increase in research output across all fields. This increase in the number of LCA studies in mining is the result of an overall increase in LCA to support decisions about mining and metals and an increase in the types of decisions about mining and metals made by stakeholders using LCA. For example, the need to rely on life cycle greenhouse gas emissions for public disclosure of climate change impacts (Agyei Boakye et al., 2023).

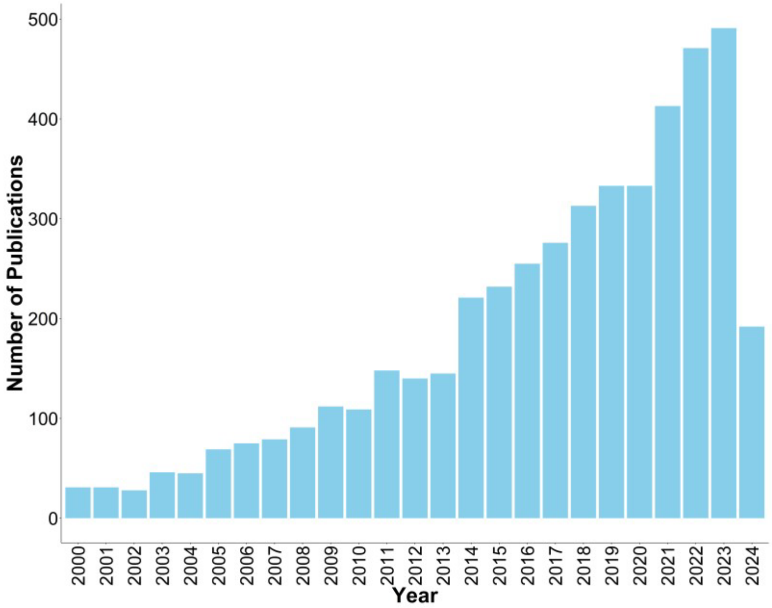

Figure 1. The trend in number of published documents in Scopus on LCA since 2000

The review also found that LCA studies in mining tend to be motivated by a desire to understand the climate change impacts of minerals and mining. For example, in their review of LCA studies of 16 mining sectors, Farjana et al. (2019) showed that global warming potential is included in the impact categories 15 out of 16 times. The next most common impact category these studies assess are energy and acidification potential. These studies only sparsely assess impact categories such as land use, particulate matter formation, and resource depletion, which impact and are of the most interest to individuals who live near mines. This raises significant environmental justice concerns as decision makers might make decisions without due consideration of individuals who live near mines and the impacts that most affect them. Especially, given that these individuals are likely to be poor and living in rural, under-resourced areas.

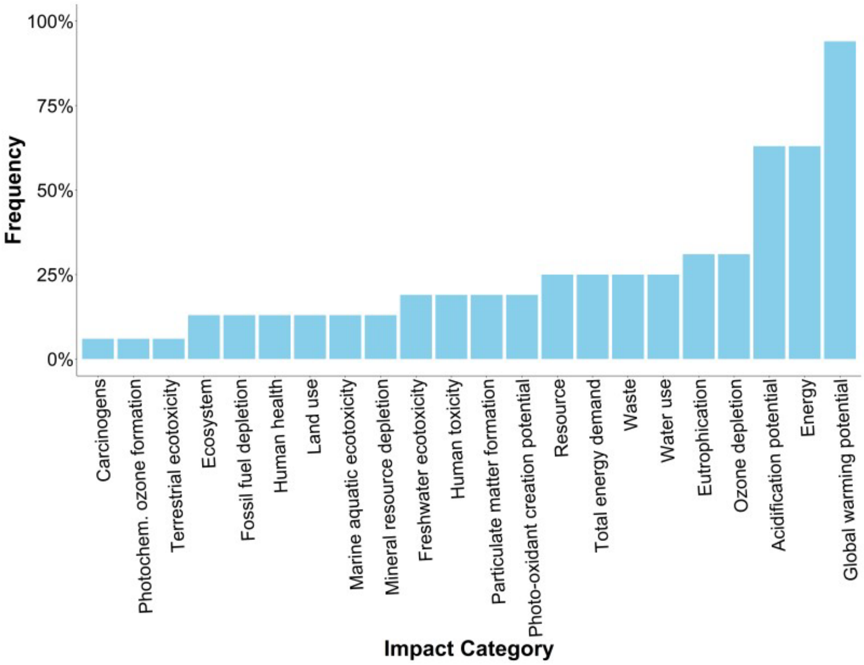

Figure 2. Impact category coverage in mining LCA studies (source data from Farjana et al (2019))

In addition to these trends, our review also shows multiple challenges that persist in mining LCAs. As indicated earlier, because of our own research interests and experience, we focused our attention on 1) data quality and gaps, 2) challenges with land use characterization, and 3) allocation issues.

The data quality and gaps issues are mainly due to the lack of publicly available (as opposed to proprietary data held by mining companies) data necessary to generate foreground data on mining and processing activities as well as the diversity of mining operations and contexts that produce the same metal or product. For example, the contexts and methods for producing copper concentrate as a primary product from an open pit copper mine in Chile differs significantly from producing copper concentrate from an underground Pb-Zn-Cu mine in the Viburnum trend in the United States. Thus, to obtain reliable data for LCA of copper the practitioner needs to obtain data on resource use and emissions from mines in all these locations as data from the open pit mine in Chile will not be applicable to the Viburnum trend in the United States.

Land use characterization challenges arise from the fact that the literature does not adequately address mining-specific land use impacts (with mining-specific impact characterization factors) and the spatial resolution of land use impact factors are often inadequate to fully characterize mineral supply chains. For example, Elshout et al. (2014), which is a pioneering study that is the basis of land use assessment in ReCiPe, only estimates characterization factors for habitats. Often, the characterization factors practitioners use to describe mining areas are those for artificial areas such as industrial parks and cities.

Allocation is germane to mining LCAs because most mines have multiple products. Although, the ISO standards (ISO, 2006) recommend that practitioners avoid allocation where possible, most mining LCAs use allocation by mass or economic value to assign environmental burdens to the various products from the same mine. Many researchers have shown that life cycle impact assessment results vary significantly based on the allocation method one uses (Nuss & Eckelman, 2014). While it is possible to avoid allocation using system subdivision or expansion (Ekvall & Finnveden, 2001), most mining LCAs continue to use allocation because it is easy leading to a situation where results have high uncertainty because of allocation strategies. Even when practitioners use allocation, it is important that the allocation strategies are consistent with the causal relationships within the system boundary and functions of the unit processes.

4. Conclusions & Recomendations

This study concludes that: (1) the application LCA to evaluate environmental impacts of mining and mining products is increasing, (2) most LCA studies focus on climate change impacts (estimating potential global warming impacts) and, often, ignore near mine impacts, and (3) methodological challenges continue to persist in mining LCA studies. The main challenges we find with LCA studies in mining are data quality and gaps, challenges with land use characterization, and allocation issues.

To address these issues, we recommend that: 1) mining LCA should increase the number of impact categories; 2) stakeholders work collaboratively to collect and aggregate proprietary data for use in LCA while protecting confidential information; 3) future research should develop regional characterization factors for life cycle land use impact assessment for mining land uses; and 4) LCA practitioners studying multi-product mining systems should first attempt to avoid allocation via subdivision or system expansion before using allocation to attribute environmental burdens and, when allocation cannot be avoided, practitioners should consider whether the basis of allocation is consistent with causal relationships and functions.

5. Acknowledgements

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6. References

Agyei Boakye, A.A., Boguski, T., Cashman, S., Koffler, C., Kreuder, A., Kumar, M., Vipparla, N. K. and Peterson, L. (2023). At the intersection of life cycle assessment and indirect greenhouse gas emissions accounting. The International Journal of Life Cycle Assessment. 28(4): 321–335.

Ekvall, T. and Finnveden, G. (2001). Allocation in ISO 14041 - a critical review. Journal of Cleaner Production, 9(3): 197-208.

Elshout, P.M.F., Van Zelm, R., Karuppiah, R., Laurenzi, I.J. and Huijbregts, M.A.J. (2014). A spatially explicit data-driven approach to assess the effect of agricultural land occupation on species groups. International Journal of Life Cycle Assessment. 19(4): 758-769.

Farjana, S.H., Huda, N., Parvez Mahmud, M.A. and Saidur, R. (2019). A review on the impact of mining and mineral processing industries through life cycle assessment. In Journal of Cleaner Production. 231: 1200-1217.

ISO 14044 (2006). Environmental Management - Life Cycle Assessement - Requirements and Guidelines, ISO 14044, International Organization for Standardization, 2006(7).

Nuss, P. and Eckelman, M.J. (2014). Life cycle assessment of metals: A scientific synthesis. PLoS ONE, 9(7): 1–12.

Responsible Sourcing

Integrated and Holistic Global Traceability Framework

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1. Introduction

Recently, legislation aimed at enhancing transparency in global mineral supply chains has been on the rise, encouraging the mining sector to implement due diligence practices (Ooms, 2022). This change has been fueled by a growing global awareness of the importance of ethical and sustainable practices in the mining industry. Consumers, increasingly aware and concerned about the social and environmental repercussions of their purchases, demand clarity about the origins of their products. They seek assurances that the minerals used do not come from conflict areas or linked to child labor, labor exploitation, or hazardous working conditions. Traceability, which refers to the ability to verify the history, location, or use of an object through proper documentation and records (IRMA, 2020; ISEAL Alliance, 2016), is crucial in this context. Mol (2015) argues traceability increases transparency and helps map and better understand issues within the supply chain, which positively impacts the environmental and social aspects. This function is particularly relevant when considering sustainability certification systems, where the documented provenance of minerals enhances the credibility and accountability of origin claims (Cartier et al., 2018).

Securing the supply chain of a product, especially its custody chain, is a critical requirement for companies aiming to maintain consumer trust and comply with increasingly stringent regulations. However, despite existing advancements and interventions, such as business solutions, certification systems, new technologies, and analytical methodologies to demonstrate transparency, many initiatives are presented as fragmented solutions without a comprehensive approach or a guiding system. This issue is exacerbated by the complexity of supply chains, which often include multiple points where minerals from different origins are mixed before refinement. This complexity poses a significant challenge to effective digitalization and tracking. In this context, the current research seeks to develop an integrated global framework for mineral supply traceability by identifying the requirements and components that this system must have, followed by the prioritization of these requirements and the design and integration of the framework.

2. Materials and Methods

The complete methodological procedure is described in Figure 1. A dual systematic literature review was conducted on the topic of traceability in the supply chain to establish the components and requirements of a framework for a mineral traceability system. For this purpose, searches were carried out in the Scopus and Web of Science (WoS) databases covering documents from 2010 onwards with the following terms: “Mineral supply chain traceability” (Scopus: 32; WoS: 30); “Mineral supply chain tracking” (Scopus: 9; WoS: 26); “Flow transparency in mineral supply chain” (Scopus: 3; WoS: 5); “Traceability technologies for the minerals supply chain” (Scopus: 13; WoS: 11); “Due diligence in the supply chain” (Scopus: 20; WoS: 7); “Transparency in mineral supply chain” (Scopus: 50;

WoS: 40); “Blockchain in mineral traceability” (Scopus: 12; WoS: 14); “Radio-Frequency Identification (RFID) in mineral supply chain” (Scopus: 2; WoS: 1); “Fingerprinting and mineral supply chain” (Scopus: 7; WoS: 6); “Chain of custody mineral” (Scopus: 17; WoS: 9). To ensure that all articles related to traceability, tracking, and due diligence along the mineral supply chain were found, the abstracts and themes of the articles were read. Finally, after excluding duplicate documents and retaining only the related documents, a total of 110 articles relevant to reviews and conferences were collected, of which 69 are related to minerals and metals.

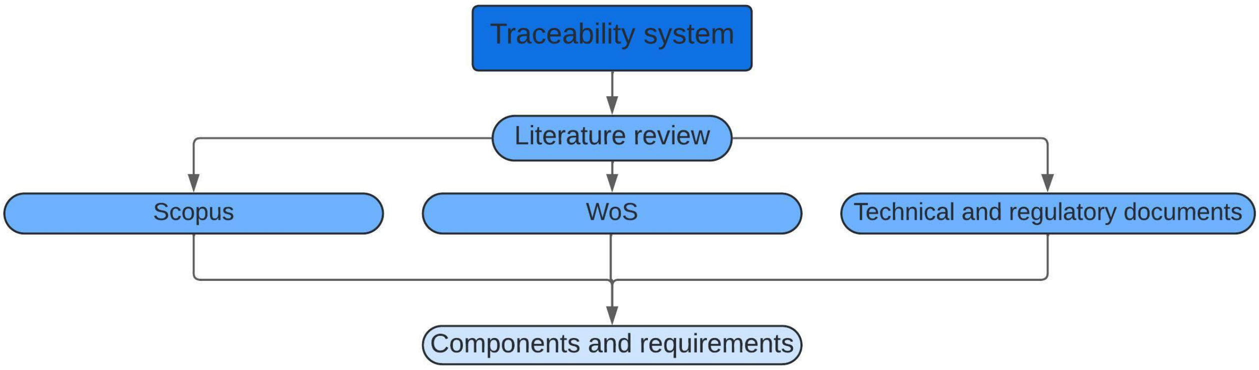

Figure 1. The methodological procedure.

Subsequently, technical and regulatory documents corresponding to frameworks (4), laws and international instruments (12), initiatives (36), manuals and reports (17), and mining standards (37) associated with due diligence, tracking, and traceability were reviewed to analyse and later extract components for the mineral traceability system. These documents correspond to a total of 106.

Frameworks consist of guidelines, recommendations, and principles that guide compliance with responsible sourcing expectations. Notable among them is the "OECD Due Diligence Guidance for Responsible Supply Chains" (OECD, 2016), which provides guidance for companies to respect human rights and avoid contributing to conflict and abuses related to their mineral sourcing, and the "ICMM Demonstrating Value – A Guide to Responsible Sourcing" that assists ICMM members in developing and improving their governance structures, business practices, and standards (ICMM, 2015).

In the field of laws and international instruments, the "Regulation of the European Parliament and of the Council Concerning Batteries and Waste Batteries" (European Commission, 2020) stands out, aiming to improve market efficiency and the sustainability of batteries throughout their life cycle, and the "Proposal for a Regulation of the European Parliament and of the Council Establishing a Framework for Ensuring a Secure and Sustainable Supply of Critical Raw Materials" (European Commission, 2023), along with the "Dodd-Frank Wall Street Reform and Consumer Protection Act" (U.S. Congress, 2010), represent significant efforts to enhance transparency and accountability in mineral sourcing and protect consumers.

Recently, in response to demands for transparency, numerous initiatives, projects, and manuals have emerged to promote and guide sustainable practices in the supply chain. Among these, associated with traceability, notable initiatives include companies such as Valcambi Green Gold (Valcambi, 2023) to trace gold from mines that meet strict sustainability benchmarks, and Trace4EU (Spherity, 2022), which aims to design and implement comprehensive solutions for product and data traceability.

Finally, standards are defined as technical documents or sets that establish sustainability and promote best practices. Notable standards include IRMA, applied to all extracted materials (e.g., minerals, metals) (IRMA, 2024); RJC, applied to gold, silver, PGM, diamonds, and colored gemstones (RJC, 2024); and The Copper Mark, applied to copper, lead, molybdenum, nickel, and zinc (The Copper Mark, 2024).

3. Results

Table 1 summarizes the main findings obtained from the documents analyzed. The information was classified into 5 main categories, whose factors are essential for developing a traceability system.

In category A, factor A1 highlights the importance of certifications and standards, elements that not only validate ethics and environmental quality but also maintain the integrity of minerals from the mine to the market. Category B emphasizes the innovative solutions emerging in the field of minerals; although it is not possible to trace minerals back to a specific mine, determining the origin can help validate the country-of-origin claims made by companies (Cartier et al., 2018). Technologies like blockchain, known for their immutable transaction records, have gained popularity. However, before adopting blockchain technology, it is crucial to evaluate certain aspects. Calvão & Archer, (2021) point out that the lack of interoperability among different blockchains can hinder data exchange; moreover, its use could centralize control of supply chains in the hands of a few, thereby limiting transparency and the democratization of the process.

Category C highlights factor C1, essential for developing systems that prevent the mixing of sources along the supply chain, ensuring the traceability of products, processes, and inputs. These systems must protect the customer against fraud and commercial disputes and ensure product safety, quality, and control throughout the supply chain (Pasvanka et al., 2019). Category D prioritizes goods from artisanal miners and environmental sustainability. A traceability system should include support measures for artisanal miners through local facilitation and financing centers (Nathan & Sarkar, 2010). Finally, Category E highlights factor E2, which advocates for the implementation of training and support measures, as suggested by Tröster & Hiete (2019). These measures aim to accelerate the acceptance and adoption of traceability systems, which is crucial to improving their effectiveness in the global mineral supply chain.

4. Final Comments and Next Steps

The research conducted allows for an initial approach to developing an effective and efficient mineral traceability system. Critical components and fundamental requirements such a system should meet to ensure successful implementation have been identified. However, traceability in the minerals supply chain continues to present significant challenges due to the complexity and variability of global supply chains.

It is recommended that the next steps should include performing a detailed subcategorization of the identified factors into more specific sub-factors. This will allow for a more granular and focused evaluation, facilitating the integration and operationalization of the traceability system. Each sub-factor should be meticulously designed to address the particularities of different geographical contexts, regulatory regimes, and various types of minerals.

To ensure an effective and result-oriented implementation, the Fuzzy TOPSIS method will be employed to prioritize the traceability system's components. This method, which uses fuzzy logic to handle the uncertainty and imprecision typical in multiple criteria evaluation, is ideal for this type of analysis due to its ability to generate a clear hierarchy based on the relative importance of each factor. Fuzzy TOPSIS will allow for precise evaluation of the system's critical components, considering both their potential impact on the supply chain traceability and the limitations and challenges.

Table 1. Factors and requirements for a comprehensive traceability system.

Category A: Governance and Compliance

N°	Factor	Definition
A1	Certifications and Standards	It combines third-party auditing to ensure ethical, environmental, and quality standards with a chain of custody to maintain the integrity of minerals from mine to market. It encompasses specialized certification systems and traceability models such as identity preservation and mass balance, includes mechanisms for on-site audits, claims, and sustainable practices, and ensures proper documentation and separation of certified and non-certified minerals along the supply chain.
A2	Due diligence	Ensures that minerals are sourced responsibly and traceably, with due diligence to assess their origin and presence, especially in conflict zones. This includes ethical sourcing measures and certifications of the absence of conflict and illegal exploitation.
A3	Legislation and reporting	Compliance with legal frameworks and reporting requirements, the development of traceability programs that comply with regulations such as the SEC, and ensuring transparency.
A4	Governance mechanism	Governance structures and mechanisms that improve ethical practices in the supply chain. It focuses on identifying conflict-free smelters and strengthening governance at key stages, such as refineries, to ensure credibility and trust in the traceability chain. It also promotes shared responsibility among stakeholders to distribute compliance burdens and maintain traceability throughout the supply chain.

Category B: Technology and Analytics

N°	Factor	Definition
B1	Analytical techniques	It emphasizes advanced scientific methods and technologies, such as LA-ICP-MS, stable isotope ratios, and fingerprinting, to trace and verify the origin of minerals and gemstones. It includes various analytical techniques, such as spectral and trace element analysis, crucial for determining material provenance, reducing false positives, and confirming authenticity.
B2	Blockchain technology	This subcategory highlights blockchain technology as a secure and transparent method for managing mineral supply chain data, verifying geographic origins, and improving accountability. It integrates blockchain with IoT, smart contracts, and AI to manage digital identities, track transactions, and streamline traceability operations.

Category C: Supply chain management and integrity

N°	Factor	Definition
C1	Supply chain integrity	Ensures the integrity of the supply chain, prevents the mixing of minerals from various sources, and maintains traceability from mine to market. It includes fraud prevention and litigation protection, thus increasing consumer confidence and product safety.
C2	Data management	It focuses on robust data management in mineral traceability, involving the collection, processing, and management of traceability information through interconnected platforms. It addresses data fragmentation, ensures accuracy and reliability, and coordinates documentation and traceability at all stages of production and across stakeholders to balance transparency with confidentiality.
C3	Supplier relations	It addresses the management and improvement of supplier relationships within the mineral supply chain, focusing on clear role definitions, responsiveness, and informed interactions between parties. It also includes collaborative efforts between companies in the supply chain and fostering relationships with stakeholders to improve collaboration, transparency, and smooth supply chain operations.

Category D: Social and environmental impact

N°	Factor	Definition
D1	Support for artisanal mining	Supporting marginalized and small-scale miners by integrating them into the benefits of mining, to improve their livelihoods and community well-being through local support and financial centers. It promotes social justice and economic equity by ensuring traceability efforts strengthen artisanal miners' confidence and access to responsible sourcing practices.
D2	Environmental sustainability	Focuses on ensuring that mining practices are environmentally responsible, emphasizing compliance with environmental standards and ESG considerations. It incorporates advanced techniques and technologies to monitor and manage environmental impacts, including carbon emissions and the environmental footprint of mining activities.
D3	Community involvement	To avoid top-down impositions, local communities should be involved in the traceability process, using fair trade labeling and participating in decision-making.
D4	Social responsability	It covers companies' ethical obligations to stakeholders and communities, focusing on CSR/ESG activities, transparent public payments and fair practices.

Category E: Performance and Evaluation

N°	Factor	Definition
E1	Monitoring	Continuous evaluation of the traceability system to optimize performance and address issues. It involves monitoring efficiency, evaluating smelting and mining operations, identifying supply chain bottlenecks, and analyzing commercial data.
E2	Training and capacity building	Improving the skills and knowledge essential for effective traceability, incorporating training, capacity building, and support systems for stakeholders. It includes change management and blockchain technology training to ensure that all participants can competently use digital platforms and contribute to the traceability process.
E3	Evaluation and improvement	Evaluate the effectiveness of the traceability system and implement improvements. It involves conducting audits, evaluating supply chain performance, optimizing blockchain solutions based on feedback, and designing automated systems to drive efficiency and transparency.

5. Acknowledgement

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6. References

Calvão, F. and Archer, M. (2021). Digital extraction: Blockchain traceability in mineral supply chains. Political Geography. 87: 102381.

Cartier, L.E., Ali, S.H. and Krzemnicki, M.S. (2018). Blockchain, Chain of Custody and Trace Elements: An Overview of Tracking and Traceability Opportunities in the Gem Industry. The Journal of Gemmology. 36(3): 212–227.

European Commission (2020). Proposal for a Regulation of the European Parliament and of the Council concerning batteries and waste batteries, repealing Directive 2006/66/EC and amending Regulation (EU) No 2019/1020.

European Commission (2023). Proposal for a regulation of the European Parliament and of the Council establishing a framework for ensuring a secure and sustainable supply of critical raw materials and amending Regulations (EU) 168/2013, (EU) 2018/858, 2018/1724 and (EU) 2019/102.

ICMM (2015). Demonstrating value, A guide to responsible sourcing. Retrieved from: https://www.icmm.com/website/publications/pdfs/mining-metals/2015/guidance_responsible-sourcing.pdf?cb=13366

IRMA (2020). Chain of Custody Standard for Responsibly Mined Materials. Retrieved from: https://responsiblemining.net/wp-content/uploads/2020/11/IRMA-Chain-of-Custody-Standard-DRAFTv1.0-October2020.pdf

IRMA (2024). Standard. Retrieved from: https://responsiblemining.net/what-we-do/standard/

ISEAL Alliance (2016). Chain of custody models and definitions. Retrieved from: https://www.isealalliance.org/sites/default/files/resource/2017-11/ISEAL_Chain_of_Custody_Models_Guidance_September_2016.pdf

Mol, A.P.J. (2015). Transparency and value chain sustainability. Journal of Cleaner Production. 107: 154–161.

Nathan, D. and Sarkar, S. (2010). Blood on Your Mobile? Economic and Political Weekly. 45(43): 22–24.

OECD (2016). OECD Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas (Third). OECD Publishing.

Ooms, M.E.A.A.M. (2022). Risk-based due diligence reporting in global mineral supply chains and the rule through transparency. The Theory and Practice of Legislation. 10(1): 48–66.

Pasvanka, K., Tzachristas, A. and Proestos, C. (2019). Quality Tools in Wine Traceability and Authenticity. In Quality Control in the Beverage Industry. 17: 289–334.

RJC. (2024). Standards. Retrieved from: https://www.responsiblejewellery.com/standards/

Spherity (2022). Spherity will build Supply Chain Provenance in EBSI TRACE4EU project together with world-leading partners. Retrieved from: https://medium.com/spherity/spherity-will-build-supply-chain-provenance-in-ebsi-trace4eu-project-together-with-world-leading-198e2447625

The Copper Mark (2024). Standards. Retrieved from: https://coppermark.org/standards/

Tröster, R. and Hiete, M. (2019). Do voluntary sustainability certification schemes in the sector of mineral resources meet stakeholder demands? A multi-criteria decision analysis. Resources Policy. 63: 101432.

U.S. Congress (2010). Dodd-Frank Wall Street Reform and Consumer Protection Act (YPFS Documents, Vol. 162). Retrieved from: https://elischolar.library.yale.edu/cgi/viewcontent.cgi?article=1210&context=ypfs-documents

Valcambi (2023). Green Gold. Retrieved from: https://www.valcambi.com/accreditations-compliance/green-gold/

Exploring the Dimensions of Transparency in Mineral Supply Chains from the Lens of Chain of Custody: An Analysis of the Chain of Custody Standards

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1. Introduction

The repercussions of the mining industry's malpractices and socio-environmental and economic impacts induced an evolving landscape of regulations, compelling organizations to demonstrate responsible sourcing of materials. van den Brink et al. (2019) suggested that chain of custody (CoC) is one of the approaches used to show responsible sourcing by validating material stewardship and responsible production claims and is realized by tracking the material as it moves down the supply chain (Levin et al., 2015). Apart from contributing to traceability, tracking facilitates transparency and is dependent on transparency for its realization (Cartier et al., 2018; ISO/ DIS 22095, 2019), thereby making it an integral component of CoC. Various CoC standards in the mining industry have not addressed this concept as explicitly as traceability.

From the point of view of scientific studies, conceptual research on supply chain transparency is available. It addresses aspects like why transparency is required (Dietrich & Melcher, 2022) and the importance of sourcing responsibly (van den Brink et al., 2019). EgelsZandén et al. (2015) deduced that achieving transparency in the supply chain is vastly limited for two reasons: Firstly, because of the variations in the definition of the term transparency, which leads to exploring only one of its dimensions, and secondly, because of the lack of practical implementation of the theoretical frameworks. The challenge is even further compounded when considering transparency in the context of CoC. For developing the CERA Chain of Custody Standard (CCS) within the MaDiTraCe project, the gaps in the CoC standards and challenges of transparency are identified and addressed by introducing a novel classification for transparency through the lens of CoC. It does so by answering two questions:

RQ1: What are the relevant dimensions of transparency concerning a CoC system?

RQ2: To what extent have the current standards addressed these dimensions, and where are the gaps and challenges of implementing some of the key elements of the dimensions?

2. Materials and Methods

For RQ1: The main objective is to extract the dimensions of transparency from the viewpoint of CoC, and for this purpose, it is necessary to define the term transparency in the context of CoC. Formulating the definition included extracting CoC definitions from standards and research articles and isolating the features prominently highlighted in describing a CoC. For instance, it was observed that certain features, such as '*sequence of entities*,' are mentioned in all, and in sharp contrast, '*tracing back to the origin*' and '*truthfulness of claims*' are less commonly adopted. A similar approach is used for transparency like generic definitions addressing responsible sourcing were considered. Elements like '*disclosure of information*' and '*type of information*' were identified. Considering the features that recurred in the collected definitions for 'CoC and 'transparency,' a definition was proposed from which three dimensions were identified. Built on each dimension, a comprehensive literature review was conducted to determine which criteria under each dimension need to be addressed to achieve transparency.

For RQ2: Four CoC standards, Aluminium Stewardship Initiative (ASI) CoC Standard (V 2.1) Initiative for Responsible Mining Assurance (IRMA) CoC Standard for Responsibly Mined Minerals (Draft V.1.0), Responsible Jewellery Council (RJC) CoC Standard (V 2), and The Copper Mark CoC Standard (V 1) were selected for this study. The contents of the standard are assessed against the key criteria selected under each dimension of transparency and plotted in a radial chart. The gaps and challenges of each are identified. Based on the available research on transparency and the study results, general recommendations were formulated to address these issues and considered in developing the CERA CCS.

3. Results and Discussion

RQ1: Based on the adopted methodology, we propose that transparency for a CoC be defined as: '*The ability of the relevant stakeholders to verify the origin of the minerals and the claims made, through the information generated regarding the sequence of possession and the processes the minerals go through in the form of documentation and disclosure*.' Three elements can be identified per the definition: authentication of origin and claims, the means of documentation and disclosure, and the relevant stakeholders. Three dimensions are evident: What, How, and Who, and the literature review aided in identifying the relevant criteria presented in Table 1, which need to be addressed to achieve transparency.

Table 1: Chosen criteria in each dimension for further analysis

What type of information is essential for enhancing transparency	**How** is the information collected, validated and disseminated	**Who** are the relevant stakeholders in the context of the CoC
Supplier's information Material's information Financial information Process and procedure information Sustainability information	CoC document Validation Dissemination Technology	Internal stakeholders External stakeholders

RQ2: The selected CoC standards were then assessed against the chosen criteria under each dimension and evaluated to determine the extent to which they addressed the selected elements. The results of the analysis are provided in Figure 1.

It is evident from the disproportional spread of matching the prerequisites of the selected criteria in the dimensions that not all the categories that foster transparency are fully addressed. In the *what* dimension, the standards generally include all the criteria in their requirements.

However, the extent to which it addresses it varies. For instance, the information required for certification is mostly limited to their direct suppliers, and risks associated with environmental, social, or governance (ESG) aspects are embedded deep in the supply chains. Such risks can be transferred to the downstream organizations and held liable (Franken & Schütte, 2022; Fraser et al., 2020). It can be addressed by mapping supply chain actors upstream and downstream (Sodhi & Tang, 2019) and engaging with their suppliers to gain better visibility and contribute to transparency. Also, it was observed that the primary focus of the standards lies only on traceability and is considered supplementary to the sustainability standards to demonstrate responsible mining practices, like the RJC CoC standard compliments the RJC's Code of Practices. Making the sustainability information mandatory at every stage will ensure the players in each stage contribute to a greater collective effort.

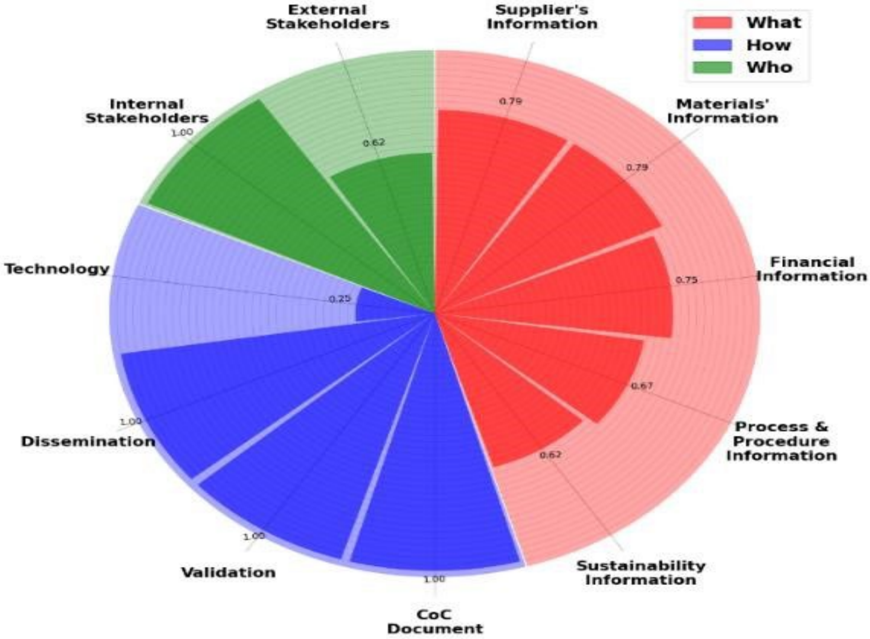

Figure 1 shows the degree to which the standards have addressed the different elements of the dimensions on average. If the elements under the dimensions were not addressed, it was given a 0; if the elements were discussed in principle and with little explanation, it was given a 0.5; and if the standards addressed the element comprehensively, it was given a 1.

For the *how* dimension, the documentation, referred to as a transfer or CoC document in the standards, is required at every stage of the supply chain, along with verification of the collected data (UN Global Compact & BSR, 2014). Complications arise when instances such as loss or modifications of physical inscriptions occur (Cartier et al., 2018), laundering minerals from areas where violence prevails and physically tagging it as originating from validated mines or accepting forged proof of payments of illegal levies (Global Witness, 2022) are all examples where conflict minerals can contaminate the supply chain and compromise the integrity of the CoC document. Although some standards have mentioned the importance of technology and the IRMA CoC standard states that it has been developed to work with existing and emerging traceability services and technologies, there are profound shortcomings in the inclusion of distinct criteria that delve into the requirements that address confidentiality, security, and determining the integrity of the information are still lacking.

Finally, in the *who* dimension, the stakeholders were broadly classified into internal and external, and all standards have sufficiently addressed the former. The internal transfer document with the related information regarding the material or product, the respective CoC model, and, in some cases, further details encompassing due diligence processes in procurement is included to establish a CoC. This information and the supplier's details are transferred to the next participant in the supply chain. As for the disclosure of audit information to external stakeholders, such as NGOs and advocacy organizations, ASI CoC provided a summary of findings, including the rating and comments explaining the reason for conformity, whereas the RJC CoC audit report was limited to delivering which criteria were applicable. Essentially, it is important to note that not all information needs to be disseminated, and it is typical for organizations to provide a summary and abstract data. Still, it has to be sufficient for stakeholders to make efficient decisions (McDermott, 2012).

4. Conclusions

This study identified three dimensions of transparency from the lens of CoC: 'What type of information is essential for enhancing transparency,' 'How is the information collected, disseminated, and validated,' and 'Who are the relevant stakeholders in the context of CoC,' and four CoC standards in the mining industry were analysed to investigate if they have addressed all the selected elements in the specified dimensions. It was determined that among all the elements, technology was the least integrated, followed by the criteria of external stakeholders. Other shortfalls were also noted in the 'what' dimension, and recommendations were formulated to serve as a basis to rectify them. These will be considered in the development of CERA CCS. It is crucial to mention that transparency in CoC is not a stagnated concept; it is important to keep up with the regulatory demands, identify emerging and existing challenges in the supply chain, and critically evaluate the potential that can influence it.

5. Acknowledgements

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6. References

Cartier, L., Ali, S. and Krzemnicki, M. (2018). Blockchain, Chain of Custody and Trace Elements: An Overview of Tracking and Traceability Opportunities in the Gem Industry. The Journal of Gemmology. 36: 212–227.

Dietrich, V. and Melcher, F. (2022). Mineral Raw Material Supply Chain Transparency and Traceability: Does Provenance Matter in the Supply Chain? BHM Berg- Und Hüttenmännische Monatshefte. 167(12): 594–597.

Egels-Zandén, N., Hulthén, K. and Wulff, G. (2015). Trade-offs in supply chain transparency: the case of Nudie Jeans Co. Journal of Cleaner Production. 107: 95–104.

Franken, G. and Schütte, P. (2022). Current trends in addressing environmental and social risks in mining and mineral supply chains by regulatory and voluntary approaches. Mineral Economics. 35(3): 653–671.

Fraser, I.J., Müller, M. and Schwarzkopf, J. (2020). Transparency for Multi-Tier Sustainable Supply Chain Management: A Case Study of a Multi-tier Transparency Approach for SSCM in the Automotive Industry. Sustainability. 12(5): 1814.

UN Global Compact & BSR (2014). A Guide to Traceability: A Practical Approach to Advance Sustainability in Global Supply Chains. Retrieved from: https://www.bsr.org/reports/BSR_UNGC_Guide_to_Traceability.pdf

Global Witness (2022). The ITSCI laundromat: How a due diligence scheme appears to launder conflict minerals. Retrieved from: https://www.globalwitness.org/en/campaigns/naturalresource-governance/itsci-laundromat/

ISO/ DIS 22095 (2019). Chain of custody - general terminology and models.

Levin, E., Cook, R., Chishugi, A., Jorns, A. and Mulumeoderhwa, P. (2015). Comparative study of certification and traceability systems. Retrieved from from: https://www.levinsources.com/assets/pages/report-promines-comparative-studycertification-traceability-systems-drc-congo.pdf

McDermott, C.L. (2012). Trust, legitimacy and power in forest certification: A case study of the FSC in British Columbia. Geoforum. 43(3): 634–644.

Sodhi, M.S. and Tang, C.S. (2019). Research opportunities in supply chain transparency. Productions and Operations Management, 28(12): 2946–2959.

van den Brink, S., Kleijn, R., Tukker, A. and Huisman, J. (2019). Approaches to responsible sourcing in mineral supply chains. Resources Conservation and Recycling. 145: 389–398.

Responsible Sourcing of EU Minerals for Sustainable & Circular Solutions

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1. Introduction

History will remember the 2020's as a new era in responsible mineral sourcing driven by sustainability reporting legislation, an emerging ESG agenda and Europe's transformation from a high to low carbon economy - a move that will forever change the way we work. The mineral sectors are committed to deliver solutions that demonstrate responsible raw material sourcing through the implementation of Best Available Technologies (BAT's) along the whole of its value chain, but challenges remain related to lengthy permitting times, energy intensive process mitigation technologies, and social acceptance of the extractive operations across EU.

The aim of this contribution is to illustrate five business models, and specific cases studies, that the mineral sectors have identified, and consider applicable along its value chain: 1. Optimisation of raw material supply; 2. Product/material life extension; 3. Resource Recovery; 4. Material as a service and 5. Industrial symbiosis. For each business model, case studies are used to demonstrate innovation in a circular economy context and respective savings whether in terms of CO_2 reduction, waste stewardship, and waste as a secondary raw material.

2. Methodology

The Circular Economy Package, also known as First Circular Economy Plan, was adapted back in 2015 (EC, 2015) to establish definitive and ambitious actions across the whole life cycle from production and consumption to waste management and market options for secondary raw materials, which includes proposed revised legislation on waste. It also included measures to help stimulate Europe's transition towards a circular economy, boost its global competitiveness, foster sustainable economic growth, and generate new jobs. After an impact assessment in 2019 it was concluded that the First Circular Economy Plan, had delivered, or was delivering on most of its 54 actions and thus it was time to assess its possible acceleration, and better alignment with the European Green deal (EC, 2019) objectives.

As a consequence, the new Circular Economy Action Plan (CEAP) was published in 2020 (EC, 2020) which announced initiatives along the entire product life cycle. These initiatives looked at how products are designed, how circular economy processes are promoted, how to encourage sustainable consumption to ensure waste is eliminated and resources used, are kept in the economy for as long as possible. It introduced legislative and non-legislative measures targeting areas where action at an EU level can bring real value added. However, the revamped product-focused plan was missing a circular economy definition for the mineral sectors and created a need for actionable items for the industry. These actionable items included a dialogue to:

- Agree on a circular economy definition for the mineral sectors;
- Agree on a visual that best represents circular economy for the mineral sectors;
- Assess if, within the minerals sectors, any existing business models already contribute to circular economy practices.

This paper explains the work done by IMA-Europe (IMA) Members to deliver on these 3 objectives.

3. Results

Within IMA a dedicated working group was created with multiple company experts to map existing industry practices and brainstorm what more could be done to accelerate the transition of the mineral sectors and contribute to a more circular economy.

3.1 Definition

After multiple sessions and iterations, the definition of circularity for minerals was developed as follows - a business model that requires an **integrated** management of resources* along the supply chain that is **technically**, **environmentally**, and **economically** viable at each stage.

*The term resources cover raw materials (primary/secondary), energy, heat, water and CO_2.

3.2 The visual of circularity for minerals

Visualisations of a circular economy business model, from a theoretical point of view, looks easy (Fig. 1), but this is not the case.

Figure 1. Policy viewpoint on the transition from linear to circular

Given the wide range of industrial minerals and end-use applications, internal discussions show that the visual for a transition from linear to a circular economy for the minerals industry is not only complex but also conditioned by technical constraints and different Member State legislation. Thus, all these factors need to be considered if a fully implementable circular-solution transition pathway is to be delivered (Fig.2).

In Europe, pressure is mounting from the Commission, Member States, rating agencies and customers for the mining and mineral sectors to demonstrate how they contribute to the provision of responsibly sourced minerals, and this can only be done through data collection, analysis, and transparent reporting. An issue still to be overcome is the existence of multiple reporting standards and range of metrics companies can adopt. However, as the new Corporate Sustainability Reporting Directive (CSRD) standards evolves this should help.

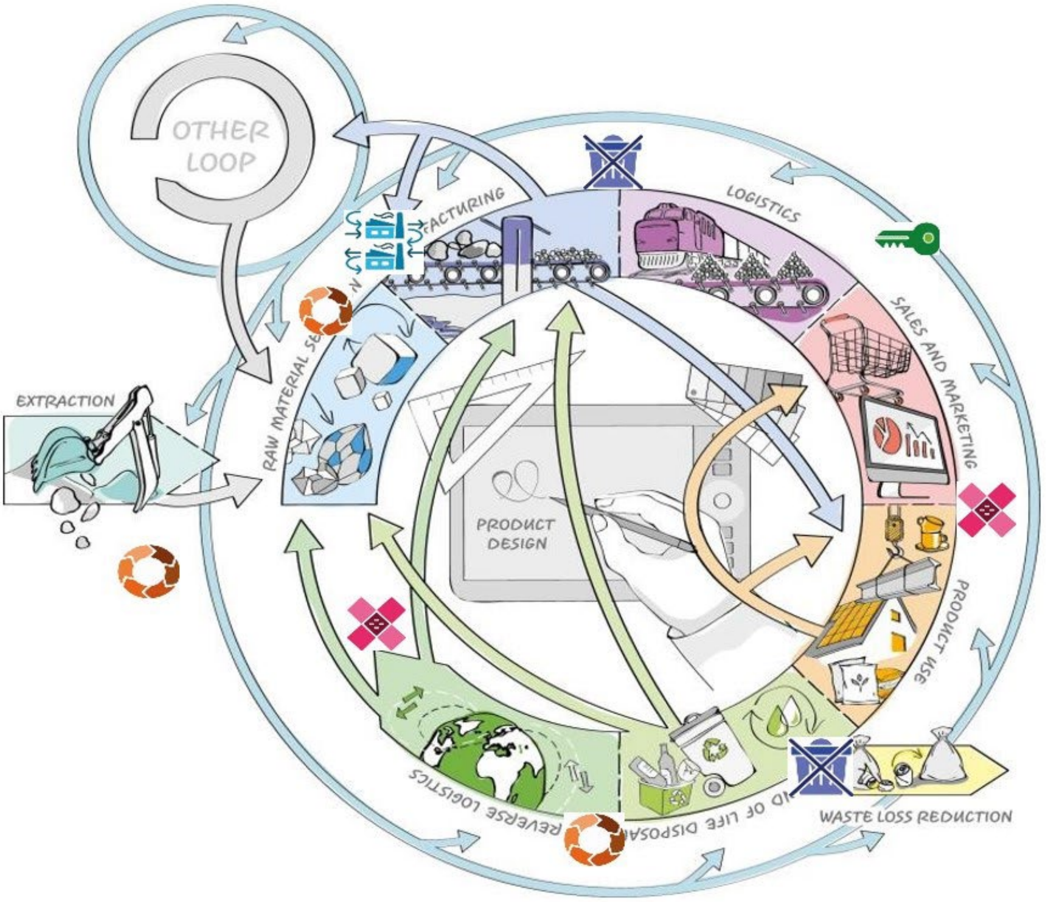

Figure. 2. Industrial mineral transition paths from linear to circular

Although the industry is moving in the right direction in terms of responsible mining practices, many mining companies are at different stages on their sustainability, compliance and ESG journey. Nevertheless, five business model areas have been identified ranging from optimisation of raw material supply through to industrial symbiosis, and for each, case studies provide examples of respective savings whether in terms of CO_2 reduction, water stewardship, or use of waste as a potential source of secondary raw material. The five areas outlined in Fig. 2 are shown in the table below (Table 1) and their respective definitions.

Some examples of these models include:

- Class recycling and recycling of ceramic waste - combing primary materials with unfired and fired scrap.
- Phosphate Recovery from wastewater purification
- Location of Percipitated Calcium Carbonate Plant in paper mills

Table.1 IMA business models of circularity of minerals

Business model	Icon	Definition
Optimized and symbiotic RM supply		Provide durable and functional materials by optimising the use of primary raw materials or combining primary and secondary raw materials
Resource Recovery		Provide material solutions extending a product's working life or facilitating product/material recycling (re-manufacture, up-cycling, eco-design or re-purposing)
Product/Material Life Extension		Minimize resources loss/waste and valorise useful resources (materials/energy) from by-products or disposed products
Material as a service		Offer material access and retain ownership to internalise the management and optimization of the circular resource
Industrial Symbiosis		Develop a network of diverse organisations to create and share mutually profitable material flows that may also improve technical processes

4. Conclusions

History will remember the 2020's as a new era in responsible mineral sourcing. The mineral sectors fundamental challenge is to develop appropriate strategies to maximise the value of primary and secondary raw materials and re-shape perceptions of customers and consumers. Only through quantification and demonstration can industry show how it is reducing its environmental footprint and be recognised as 'responsible'; thus, doing its part to deliver on climate change, Green Deal and United Nations Sustainability Development Goals (SDG's). The time for action is now and the work done by IMA experts demonstrate that responsible sourcing and circular practices from the minerals industry are not new.

5. References

European Commission (2015). Circular Economy Package (also known as First Circular Economy Plan).

European Commission (2019).The European Green Deal - European Commission.

European Commission (2020). New Circular Economy Action Plan EUR-Lex - 52020DC0098 - EN - EUR-Lex.

The Potential for Blockchain Technologies in the Mining Industry

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Abstract

The mining industry is well-versed with smart technology and has leveraged its benefits for decades. As the technology has evolved, it has been tested and deployed in the mining industry to optimize the process chain. The mining industry also operates within disparate global landscapes marred by human rights violations, concerns around child labour, and conflict minerals (Bebbington and Bebbington, 2018). In recent years, these challenges have led to the emergence of provenance, traceability, and transparency as key aspects of sustainable mining and have resulted in a 'new political economy of mineral extraction' (Seagle 2012). The principles of sustainability and transparency are linked with conservation, life-cycle analysis and digitization, and other aspects of 'extractivism' (Calvão and Archer 2021).

Governments in Europe, North America, Africa, and Oceania are looking to blockchain and related technologies to provide transparency and traceability across a complex mining value chain. These technologies present opportunities and challenges for a global mining industry faced with ever-evolving geopolitics as the globe sets its sights on energy transition, carbon neutrality, and sustainability in the coming decades. This paper seeks to outline these opportunities and challenges and presents a case for industry-government partnerships in forging new institutional structures supporting transparency and traceability in coming years.

References

Bebbington, A. and Bebbington, D.H. (2018). Mining, movements and sustainable development: Concepts for a framework. Sustainable Development. 26(5): 441-449.

Calvão, F. and Archer, M. (2021). Digital extraction: Blockchain traceability in mineral supply chains. Political Geography. 87: 102381.

Seagle, C. (2012). Inverting the impacts: Mining, conservation and sustainability claims near the Rio Tinto/QMM ilmenite mine in Southeast Madagascar. The Journal of Peasant Studies. 39(2): 447-477.

Sustainable Mining

How can Green Financing Impact the Sustainability of Mining Operations?

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1. Introduction

Green financing, which emerges as a new model to combat climate change and support environmentally friendly projects, encompasses all financial instruments to fund activities that promote environmental, social, and economic sustainability (Falcone, 2020). The mining projects advocating adaptation and mitigation strategies can be supported by green financing. These projects include transiting decarbonization through renewable energy sources, reducing energy requirements, enhancing water conservation, and minimizing the impact of waste and tailings. Eligibility criteria may also consider greenfield versus brownfield projects, commodity type, the previous environmental record of the mining corporation, and regional delicacies of the project location. In a green financial framework, policies and institutional arrangements are aimed at channelling private funds into green industries through various financial services such as green bonds, ESG funds (e.g., mutual funds, ESG Exchange-traded funds, and ESG index funds), and sustainability-linked loans (Bhatnagar & Sharma, 2022).

2. Green finance in mining industry

The mining sector plays a crucial role in global economies by providing essential raw materials but also poses significant environmental challenges through the energy-intensive extraction and processing of minerals (Yousefian et al., 2023). Accordingly, the pursuit of sustainability within the mining industry has become a key focus of research, investigating innovative ways to minimize the sector's environmental footprint. In this context, the adoption of green finance principles is increasingly seen as a critical tool for supporting these sustainability initiatives in the mining sector. Green finance holds the potential to transform the mining sector. Engaging the green finance market makes it possible to finance environmentally friendly projects within the industry (He & Liu, 2023). This financial support can drive the implementation of sustainable practices, from reducing carbon emissions to improving waste management and advancing responsible mining methods.

However, the effectiveness of green finance and the overall sustainability of the mining sector are influenced by various factors that vary from country to country. Consequently, the practical impact of these initiatives can vary significantly (Yan et al., 2023). Recent studies highlight the role of green finance in promoting sustainability within the mining industry. Zheng et al. (2023) explore how sustainable investment and ESG criteria are integral for shaping green finance practices in the sector. Chu et al. (2024) find that a 1% increase in green finance correlates with reduced CO_2 emissions in the mining industry across 12 Asian economies, suggesting that green investments can lead to cleaner technologies and practices. Tang and Qin (2024) support the positive impact of the green finance market on reducing carbon emissions in the mining industry across BRICS nations.

Lastly, Ma et al. (2024) demonstrates that both green bonds and green credits significantly lower CO_2 emissions from the extraction of minerals for Electric Vehicles in ten APEC countries, with a notable decrease in emissions tied to each increase in green credit.

3. Greenwashing

Green bonds are widely acknowledged as a significant mechanism for mobilizing financial resources to facilitate clean and sustainable investment initiatives. In theory, green bonds issued by corporations are considered potential drivers for enhancing investments in environmentally friendly initiatives, thus promoting corporate sustainability efforts. In practice, however, funds raised from certain bond issuances are not entirely invested in green projects; instead, they are allocated to cover daily working costs or corporate debts (Cheng & Wu, 2024). This raises concerns about 'greenwashing,' where companies claim to prioritize green investments to attract socially responsible investors while their actual environmental impact remains minimal.

Therefore, despite the increasing adoption of green bonds in corporate finance, there still needs to be a more comprehensive understanding regarding their actual influence on issuers' environmental commitments. Should greenwashing predominate, the effectiveness of green bonds in realizing substantial environmental benefits remains questionable. Alternatively, if green bonds are indeed utilized to fund genuine environmentally sustainable projects, an observable improvement in the environmental stewardship of the involved companies is expected. This positions green bonds as a robust measure of a company’s commitment to environmental sustainability (Fatica & Panzica, 2021).

4. Conclusions

To promote a genuinely sustainable mining sector, countries must customize their green finance strategies to fit their specific conditions, thereby promoting alignment with sustainable practices. This involves encouraging financial institutions to invest in environmentally responsible mining projects through incentives and supportive frameworks, particularly focusing on sustainable financing and green bonds. Additionally, the adoption of advanced technologies such as blockchain and artificial intelligence is crucial. These technologies can improve the transparency and efficiency of green finance, ensuring that investments are directed towards sustainable mining initiatives.

Moreover, urban integration of renewable energy sources is essential to reduce the mining industry's carbon footprint and support a cleaner energy ecosystem. Policymakers should also focus on long-term commitments to green policies, recognizing that the benefits of such initiatives unfold over time and require sustained effort to achieve significant environmental improvements.

Consequently, it is essential for corporations to extend beyond simple compliance with regulatory mandates by adopting stricter environmental guidelines, increasing the transparency of their environmental reporting, encouraging broader community involvement, and enabling more rigorous monitoring by non-governmental organizations. Implementing these actions will improve the effectiveness of environmental regulations and cultivate a cooperative relationship between companies and the community, which is crucial for building a sustainable future.

5. References

Bhatnagar, S. and Sharma, D. (2022). Evolution of green finance and its enablers: A bibliometric analysis. Renewable and Sustainable Energy Reviews. 162: 112405.

Cheng, Z. and Wu, Y. (2024). Can the issuance of green bonds promote corporate green transformation? Journal of Cleaner Production. 443: 141071.

Chu, M., Li, B., Gu, W. and Dai, X. (2024). Role of green finance in enhancing the sustainability in the mining sector in Asia. Resources Policy. 88: 104473.

Falcone, P.M. (2020). Environmental regulation and green investments: The role of green finance. International Journal of Green Economics. 14(2): 159–173.

Fatica, S. and Panzica, R. (2021). Green bonds as a tool against climate change? Business Strategy and the Environment. 30(5): 2688–2701.

He, Y. and Liu, R. (2023). The impact of the level of green finance development on corporate debt financing capacity. Finance Research Letters. 52: 1–8.

Ma, X., Liu, L. and Zhang, D. (2024). How green finance tools and electric vehicles minerals sustainability are related? Resources Policy. 90: 104799.

Tang, Z. and Qin, D. (2024). Sustainable mining and the role of environmental regulations and incentive policies in BRICS. Resources Policy. 90: 104718.

Yan, X., Yang, C. and Zhang, R. (2023). How does green finance derive the resource efficiency and decarbonization of the economy? Resources Policy. 85: 103934.

Yousefian, M., Bascompta, M., Sanmiquel, L. and Vintró, C. (2023). Corporate social responsibility and economic growth in the mining industry. Extractive Industries and Society. 13: 101226.

Zheng, J., Jiang, Y., Cui, Y. and Shen, Y. (2023). Green bond issuance and corporate ESG performance: Steps toward green and low-carbon development. Research in International Business and Finance. 66(28): 102007.

Enhancing CRM Supply Resilience through SOSO Mining: A Sustainable Approach to Meeting Critical Raw Material Demands

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Keywords: Critical Raw Materials (CRMs), SOSO Mining, Sustainable Development, Supply Chain Resilience.

Abstract

The evolving dynamics of Critical Raw Materials (CRMs) supply and demand, pivotal for the advancement of the fourth industrial revolution, underscore the necessity of innovative approaches in mining practices. Among these, the concept of "Switch On – Switch Off" (SOSO) mines emerges as a crucial strategy for enhancing the resilience and sustainability of CRM supply chains. SOSO mines, characterized by their flexibility, adaptability, and minimal environmental footprint, offer a promising solution to the challenges posed by the fluctuating global market prices and the stringent requirements of sustainable development goals (“Resources-V10-I07_20240212.Bib,” n.d.). By leveraging advanced technologies, SOSO mines enable the efficient and responsible extraction of CRMs, even from low-grade deposits, thereby addressing the dual objectives of economic viability and environmental stewardship. This approach facilitates the rapid deployment and mobility of mining operations in response to favourable market conditions and minimizes the investment risks associated with conventional large-scale mining operations. The significance of SOSO mines in meeting the supply demands of CRMs is thus critical, as it ensures a steady and sustainable supply of these essential materials, reinforcing the economic resilience and technological advancement of the European Union and beyond. This Study highlights the importance of SOSO mining practices as a transformative solution for securing the CRM supply in an era marked by rapid technological development and increasing environmental consciousness.

Posters

Gender Differences in Career Success: A Brief Review of the Current Reporting Systems and their Effectiveness

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Keywords: EDI, ESG, Policies, Sustainability, Belonging, Gender Equality

Abstract

Advancing sustainability within the mining industry includes the goal of fostering greater diversity (Woźniak et al., 2022) Despite the adoption of numerous recommendations and measures in this regard, achieving a sense of belonging and retention among mining workers remains challenging. This review analyses and evaluates the effectiveness of the current reporting frameworks, utilized by the mining industry for Equity, Diversity, and Inclusion (EDI) policies. To accomplish this objective, a comprehensive benchmarking and review of the three most widely used frameworks: Accounting Standards Board (SASB), Global Reporting Initiative (GRI), and the Minning Association of Canada's industry specific Towards Sustainable Mining (TSM) standard, was conducted, alongside a cross-referencing process with the current Environmental, Social and Governance (ESG) reports generated by mining companies. The resulting evaluation provides insights into the effectiveness of these reporting frameworks (Leonida, 2022) and their recommendations in promoting retention and a sense of belonging.

References

Leonida, C. (2022). Riding the Risks and Opportunities of ESG in Mining. Engineering and Mining Journal. 223(6): 40-45.

Woźniak, J., Pactwa, K., Szczęśniewicz, M. and Ciapka, D. (2022). Declaration of the Sustainable Development Goals of Mining Companies and the Effect of Their Activities in Selected Areas. Sustainability. 14(24): 16422.

Lifecycle of Mine Water – An Essential Resource in a Circular Mine

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1. Introduction

Climate change is impacting the global water cycle, which will result in 44 million Europeans facing water shortages by 2070. The growing demand for water from various sectors, including the mining industry, is expected to increase conflicts over water resources (Gao et al. 2017). To maintain profitability and community approval, the mining sector needs to adopt sustainable and circular water management practices. The concept of "Integrated Water Management" (IWM) has emerged in water-intensive industries like mining to underscore the importance of comprehensive, sustainable water use. This approach is central to initiatives like the Blue Mining Initiative and involves careful planning, assessment, preservation, treatment, and monitoring of water use throughout a mine's lifecycle.

The main goal is to minimize mining's impact on local water resources, ensuring the protection of water quality and the sustainability of water management to reduce the water footprint without affecting production levels. Key aspects of IWM include optimizing water usage and recycling, purifying wastewater, avoiding disruption to natural watercourses, continuously monitoring water sources, raising employee and stakeholder awareness about water conservation, and involving the local community in decision-making processes. Developing effective management strategies in mining requires a deep understanding of climatic and hydrogeological conditions, and water use across the five main phases of mining—exploration, planning, production, closure, and post-mining—each evaluated for its specific water needs and potential changes in water quality.

2. Research Concept

The amount of water needed varies based on the mine type, the technologies and processes used, environmental laws, and the availability of water in the region. As each mine site is unique, one water management strategy cannot be applied to all mines, but rather an iterative planning process must be undertaken that considers holistic approaches for each individual case. Consequently, the five key stages of mining—exploration, planning, production, closure, and post-mining—are qualitative analyzed to assess how water demand and water quality change throughout these phases (Fig. 1).

The following presents a discussion of the phases and their objectives and actions for integrated water management based on initial literature research. Basically, the water demand of a raw material extraction operation is the sum of the social water demand to supply the workforce and the water demand of the raw material processing method, plus potential other water uses such as dust control.

The raw material extracted and its processing method have the greatest impact. It can therefore be assumed that the water requirement is basically similar for every mine, albeit on a different scale, and initially increases during the planning and development of the mine and reaches its maximum during production. In the post-operational phase, the extraction of raw materials is completed so that water is no longer required for active operations. Nevertheless, water is still a valuable resource in this phase, which can also be used by the neighbouring communities in this phase or can support the chosen renaturation strategy. The need for water treatment technologies is similar, but much more dependent on local conditions, particularly the existing mineralogical background and its evolution during mining and the processes used.

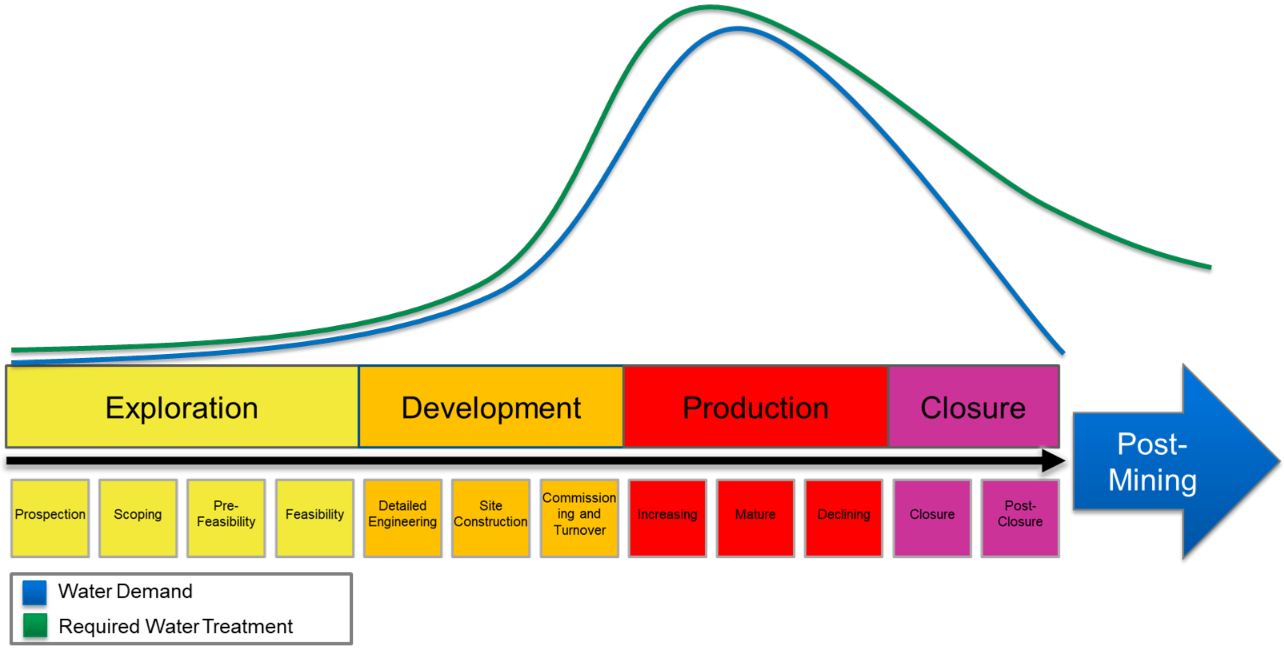

Figure 1: Simplified representation of the life phases of a mine modified from Bothe-Fiekert et al. 2023.

2.1 Exploration

During exploration the water demand is generally low, yet it is a critical time for assessing future water requirements for the project. This phase involves a thorough evaluation of the hydrogeological conditions and watersheds surrounding the deposit to preemptively identify potential impacts on local water resources. This evaluation includes collecting and analyzing data on local water bodies, their watersheds, flow paths, as well as meteorological, geological, and environmental information. The aim is to fully understand the hydrological system prior to the start of mining activities and to predict both qualitative and quantitative impacts on local water sources (Department of Water Affairs and Forestry 2008, Punkkinen et. al 2016, Wolkersdorfer et al. 2020).

At this stage, it is possible to determine not only what water resources are available, but also how the water treatment strategy will evolve. Therefore, the water management strategy for the operational phase should be outlined during exploration (Bothe-Fiekert et al. 2023). This strategy classifies water into three categories: process and gray water, natural water sources, and wastewater, each requiring specific monitoring, potential treatment and usage. Furthermore, it is important to identify water users and stakeholders nearby early on to proactively address and prevent conflicts over water use.

Water management strategies should also consider future uses in the post-mining phase to avoid costly modifications later. In regions with specific climatic challenges, such as arid areas, the focus might be on optimizing water supply, whereas in humid regions, managing excessive runoff and preventing landslides or dam failures during heavy rains are prioritized. Continuous monitoring and periodic review of water demand and quality are crucial throughout the operation. Adjustments may be necessary to adapt to changes in water availability, such as seasonal variations. In addition, special precautions are taken to minimize potential negative effects on local waters during this initial phase.

For instance, drilling must be meticulously planned as improper drilling can disrupt the water cycle and potentially lead to contamination. The proper management of chemicals and contaminated waters during exploration are essential to reduce environmental risks. Finally, exploration should consider the long-term utility of drill holes as they might be repurposed after exploration, for groundwater monitoring, aligning with the mine's overall monitoring plan.

2.2 Planning and Construction

In the planning phase of a mining project, detailed designs for the operational areas and the associated water infrastructure are developed. This phase is crucial for considering the potential future uses of the infrastructure after the mine closes. Early identification of possible usage options enables proactive technical planning, ensuring that the infrastructure is appropriately sized and stable from the beginning. Water can be used during the production phase in multible ways, such as in ore processing, cooling, or dust control, and can also support renewable energies through the implementation of pumped storage power plants in combination with renewable energy facilities like solar or wind parks, or by the implementation of (micro) hydroelectric power plants enhancing the site's energy efficiency.

The specific water usage strategy will depend on the local (hydro)geological conditions, including water availability, mineral composition, rock strength, and geothermal gradients and local sociopolitical aspects.The planning phase should integrate these considerations into a comprehensive mining plan that encompasses underground mine service water systems, mining cooling systems, and strategies for managing water inflows and civil construction involving mechanical, electrical, and instrumentation designs.

As construction at the mining site begins, the water infrastructure is also established. This marks the initial visible environmental impacts, such as changes in topography, alterations in surface runoff, and hydraulic impacts on local aquifers (Punkkinen et. al 2016). Concurrently, the water management and monitoring program is detailed further, providing precise information about estimated water flows from various plant units and the overall mining area. At this stage, it is critical to identify the aspects of mining operations that demand the most water or have the most significant impact on water quality. It is vital to assess whether process loops can be optimized and if certain areas of operation can utilize water of lower quality, reducing the need for fresh water. This approach not only helps in minimizing the environmental footprint but also enhances the efficiency and sustainability of water usage in mining operations.

2.3 Production

During the operational phase of mining, it's crucial to continuously collect data on water quality and quantity. This ongoing data collection helps to refine water balance models and update management plans. It's also important for meeting regulatory requirements, with strict monitoring and reporting to the relevant authorities necessary (Weeser et al. 2018). Feedback on water quality and quantity is also shared with stakeholders, keeping them informed.

Even though water usage strategies for the post-mining phase are typically devised during the mine planning stages, these strategies need ongoing review to ensure the existing infrastructure and the geological conditions altered by mining activities are still suitable for their intended future uses. Mining can significantly change rock engineering properties, which might affect how infrastructure can be used post-mining. sustainability and community well-being.

2.4 Closure and Post-Mining

The closure phase of a mine is a critical transition period from active raw material extraction to what is known as the post-mining phase. This phase requires meticulous planning and management of water resources to span potentially decades, aiming to safeguard the quality of life for the local population and maintain the ecological integrity of the environment. During this phase, IWM prioritizes water treatment and management strategies designed to progressively reduce water demand while ensuring long-term water quality with minimal costs and monitoring efforts.

Traditional approaches have often focused on restoring the environment to its original condition. However, this can be challenging or even unfeasible if significant alterations, such as the redirection of surface water systems, have occurred during the operational life of the mine. The closure strategy should thus balance environmental impact minimization with socio-economic considerations, considering the needs of surrounding communities and potential end-users. Key aspects of IWM during mine closure involve not only rigorous monitoring to ensure ongoing water quality but also integrating possible water uses and existing infrastructures into regional energy and water supply systems. This can help to enhance the mine's legacy and provide continued benefits to the community. Each potential water use (fig.2) requires a comprehensive risk assessment, considering both the immediate and long-term implications of the water's quality and availability.

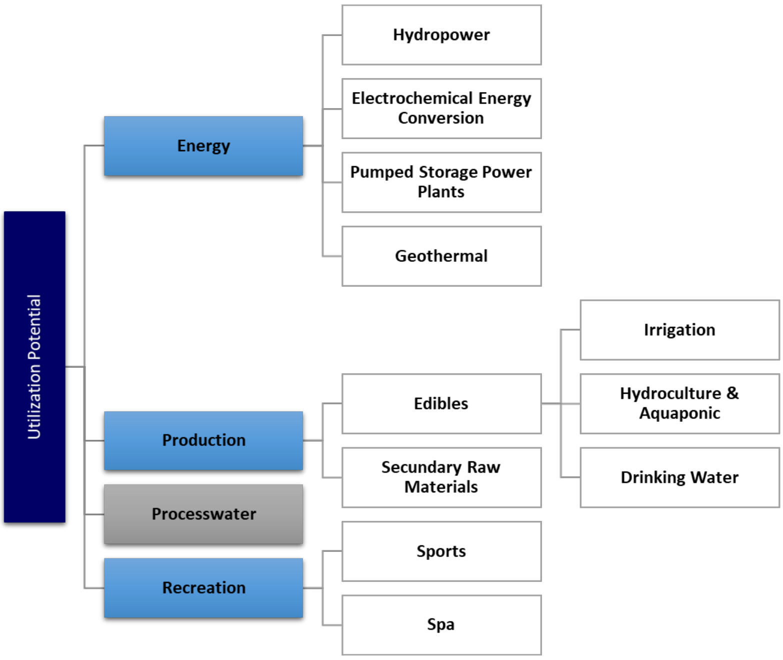

Figure 2: Overview of the various uses of mine water in the post-mining phase. These can be implemented both during active operation and in the post-mining phase. However, some of them can only be implemented if they are considered at an early stage of mine planning, as later implementation is not technically or economically feasible.

These assessments should evaluate the temporal development of water conditions to ensure sustainable usage over time. By addressing these factors, the closure phase can effectively transition a mine from extraction activities to a sustainable post-mining phase that contributes positively to the local community and the environment.

3. Conclusions

In conclusion, the pressing challenges of global warming and increasing water demand across various industries underscore the urgency for the mining sector to adopt more sustainable and circular water management practices. IWM emerges as a pivotal approach, offering a systematic framework to address these challenges effectively. Through the strategic implementation of IWM, the mining industry can ensure minimal impact on local water resources, maintain water quality, and optimize water use throughout the mine's lifecycle. By incorporating comprehensive planning, careful monitoring, and community engagement into every phase from exploration to post-mining, the industry not only upholds environmental and social responsibilities but also enhances its operational efficiency and public perception.

The detailed examination of each mining phase— exploration, planning, production, closure, and post-mining—reveals the critical importance of continuously adapting water management strategies to meet both current and future needs. As the mining operations evolve, so too must the strategies to mitigate environmental impacts and support the surrounding communities. The success of these efforts will not only preserve essential water resources but also potentially transform mining sites into long-term assets for regional water supply and energy generation, showcasing a commitment to sustainability and strengthening community ties. The transition towards sustainable practices through the Blue Mining Initiative and similar efforts marks a progressive step towards reconciling industrial activities with the imperative to protect and sustain our planet's natural resources.

4. References

Bothe-Fiekert, M., Binder, A., Nowosad, S.P., Apollo, F. and Langefeld, O. (2022). Lifecycle of Mine Water. In: W. Frenz und A. Preuße, Hg. Yearbook of Sustainable Smart Mining and Energy 2022. Technical, economic and Legal Framework // Technical, Economic and Legal Framework. Springer International, Springer Nature Switzerland; Imprint Springer, S. 75-103.

Department of Water Affairs and Forestry (2008). Best Practice Guideline A6: Water Management for Underground Mines.

Gao, L., Bryan, A., Liu, B., Li, J., Chen, W., Liu, Y. and Barrett, R.D. (2017). Managing too little and too much water: Robust mine-water management strategies under variable climate and mine conditions. Journal of Cleaner Production. 162: 1009-1020.

Punkkinen, H., Räsänen, L., Mroueh, U-M., Korkealaakso, J., Luoma, S., Kaipainen, T., Backnäs, S., Turunen, K., Hentinen, K., Pasanen, A., Kauppi, S., Vehviläinen, B. and Krogerus, K. (2016). Guidelines for mine water management. VTT Technology. pp. 266.

Weeser, B., Kroese, J.S., Jacobs, S., Njue, N., Kemboi, Z., Ran, A. and Breuer, L. (2018). Citizen science pioneers in Kenya - A crowdsourced approach for hydrological monitoring. Science of the Total Environment. 631: 1590-1599.

Wolkersdorfer, C., Nordstrom, D.K., Beckie, R.D. et al. (2020). Guidance for the Integrated Use of Hydrological, Geochemical, and Isotopic Tools in Mining Operations. Mine Water and the Environment. 39: 204–228.

CRM Valorization in E-waste: the PCB Case Study

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Abstract

In Europe, copper is predominantly used in electrical and conductivity applications and an increase of 35% in copper demand is expected by 2050. The European Union has recently assigned copper as a "strategic raw material", in the 2023 Critical Raw Materials Act. Currently, recycled copper material fulfils at least half of the copper demand in Europe. However, there is still potential to further increase the European recycling rate. Electronic waste (e-waste) is considered one of the most important sources for secondary copper since it represents one of significant portion of municipal waste flow in terms of copper content. It accounts for about 11% of the total copper waste in the EU. Printed circuit boards (PCBs) are present in quite all the WEEE, and they are made of layers of copper and glass fibers, coated in epoxy resin (generally green), having in from 20% to 40% wt of copper in their composition. Electronic components (ECs), such as resistors, capacitors and inductors are soldered to the circuit board.

The heterogeneous PCB composition hinders the process of recovering the materials, making it a very time- consuming and expensive. Several studies have been developed for efficient, eco-friendly, and economic recycling process for these components. The most effective way chosen by the authors is initially through mechanical processes which are environmental-friendly and have lower cost, then applying green chemical treatments to refine the product and to obtain the pure metal. Comparing results obtained with non-selective treatment and treatment of the board and the electronic components separated, the choice of perform a removal of the ECs was taken.

To perform a prior separation of the ECs attached to the PCB, removing the integrated circuits, capacitors, heat sinks, inductors, among others, leaving only the printed circuit board Osai's built an equipment capable of selectively disassemble the ECs and sorting them into groups, concentrating the materials which facilitates the recycling process.

The process consists of detaching components from printed circuits with thermo-mechanical treatments. The designed machine is made of rotating cylinder sieve, capable to reach and maintain a controlled temperature of approximately 250°C, in which is close to the melting temperature of the solder. The combination of mechanical treatments, temperature and kinetic energy promote the detachment of the components from the relative circuit boards. After, the selection and segregation of the components is done based on characteristics (geometry, weight and size) refining the quality and selectivity of the output. Thus, the boards and each component can be treated with the appropriate measures, achieving a high level of separation, and maximizing its recovery and recycling.

The boards free from EC are subjected to mechanical processes, consisting in comminution, followed by grain size classification. After, magnetic and electrostatic separation are carried out, thus obtaining a product with a higher concentration of Cu with minor contents in Ni, Au, Sn etc.

The Future Mining Engineer from Research to Entrepreneur

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Keywords: Entrepreneurship; EIT Raw Materials; Circular Economy; Mining; Research to Entrepreneur

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Abstract

Along with the creeping advance of automated mining units and ultimately systems the nature of the work is bound to change in the mine environment. The required skillsets that mining education graduates need to possess will only resemble what traditionally has been the case. Many of the mining engineering graduates of the future will find their place not working for mining companies per se, but rather in the METS (mining equipment, technology and services) sector or OEMs (original equipment manufacturers). In this environment, success is measured by the ability to transform ideas into commercial products that serve mining companies and operations. The future success stories will be counted by licensed IP or products. The acquisition of these skills begins with the delivery of entrepreneurship education as part of an integrated curriculum involving case studies, internships, competitions and providing a platform and resources to start a business. Through programming and support provided by the European Institute of Technology Raw Materials Innovation Centre (EIT Raw Materials), has been successful in turning young engineers' ideas into fledgling commercial enterprises offering innovative solutions to the minerals sector. This paper looks at how entrepreneurship education is shaping the mining engineer of the future and helping to prepare them for a dynamic and rewarding career.

Investigating the Multidimensionality of Mine Closure: The Case of the Greek Surface Coal Mines

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Abstract

Considering the planned gradual phase-out of coal mining in Greece, ensuring a sustainable mine closure is critical. In this context, many discussions, revisions, and interactions have been employed to configure new conditions in strategic mine planning and create the need to conduct revised environmental impact assessment studies for the earlier mine closure. Combining these steps and considering the future land uses in reclaimed or undisturbed mining areas, preparing a spatial plan (Politis, 2020) is one of the main procedures for mine closure planning. All those activities should always comply with the National Energy and Climate Plan (NECP) liabilities, constituting the country's roadmap for the energy transition (NECP, 2023). The objective of the present study is to investigate the multiple dimensions of mine closure activities, considering regulations and legislation related to reclamation planning. Furthermore, it aims to prepare a hierarchical workflow model for defining the steps of a successful transition to post-mining land uses. In this framework, the responsibilities of the involved organizations (mining companies, public bodies, and other stakeholders) are examined to achieve an effective and sustainable mine closure. In addition, a semi-quantitative risk assessment approach is proposed concerning the developed model. In this direction, the environmental, geochemical, and geotechnical stability are considered to ensure the multi-parametric equilibrium of the mine closure processes.

References

National Energy and Climate Plan (2023). Preliminary Draft Revised Version. Hellenic Republic Ministry of Environment and Energy.

Politis G. (2020). Legal Analysis on Special Spatial Plan (SSP). The World Bank. Presented to: The European Commission, Ministry of Environment and Energy, the Governor of Western Macedonia and the Coal Regions in Transition Working Group for Western Macedonia.

International Approach to Regulating Conflict Mineral Resource Trade: Effectiveness and Challenges of KPCS

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1. Introduction

The relationship between rough diamonds and conflict is very close. Rebel groups have used rough diamonds to finance their wars and increase their private incomes. Such rough diamonds are widely recognized internationally as "conflict diamonds"(Lujala et al., 2005). To address the conflict diamond problem, the "Kimberly Process Certification Scheme" (KPCS) was implemented in 2003.

Few studies exist that empirically study the effects of KPCS. Therefore, the purpose of this study is to empirically verify and present the effects of KPCS.

2. Materials and Methods

2.1 Network Analysis

Using trade data on rough diamonds for industrial and gemstone use1, which are the subject of the KPCS, we conducted a network analysis and made comparisons before and after the KPCS.

2.2 Effectiveness estimation of KPCS

Using countries with secondary deposits of rough diamonds2 at high risk of smuggling as the treatment group and other developing countries as the control group, we estimated the effect of KPCS on conflict using the difference-in-differences (DID) method for the average incidence of conflict between "armed conflict in which one party is a national government" (national conflict) 3and "armed conflict in which neither party is a national government" (Non-State Conflict)4. Prior to implementing DID, we used propensity score matching to select a control group with similar covariates to the treatment group.

3. Results and Discussion

3.1 Network Analysis

A comparison of network features before and after KPCS for the industrial and gemstone rough diamond trade network showed that the modularity values increased and the community structure was strengthened in the industrial diamond rough trade network, as shown in Table 1.

1. Trade data were obtained from World Integrated Trade Solution (WITS).
2. Using DIADATA (Gilmore et al., 2005), these countries were identified.
3. Using UCDP/PRIO Armed Conflict Dataset version 23.1
4. Using UCDP Non-State Conflict Dataset version 23.1

On the other hand, Table 2 shows that the values of modularity did not change and community structure was not strengthened in the trade network of rough gem diamonds. This can be attributed to the difference in supply chain structure between the two. Differences in community structure changes were observed between industrial and jewelry, but it is unclear if this is due to the KPCS effect.

Table 1. Feature values of the industrial gem diamond trade network in 2002 and 2007

	2002	**2007**
Nodes	89	85
Edges	359	324
Density	0.046	0.045
Average degree	4.034	3.812
Average weighted degree	1730	2678
Average clustering coefficient	0.395	0.349
Modularity	0.302	0.407

Table 2. Feature values of the rough gem diamond trade network in 2002 and 2007

	2002	2007
Nodes	103	75
Edges	387	400
Density	0.037	0.072
Average degree	3.757	5.333
Average weighted degree	243248	465397
Average clustering coefficient	0.372	0.435
Modularity	0.218	0.203

In order to investigate the effect of KPCS, we focus on the nodes that have disappeared from the network, especially focusing on gemstones with high smuggling risk. From Table 2, many nodes were removed from the network after KPCS enforcement. Among these nodes, Figure 1 shows a summary focusing on Africa, which has a large number of rough diamond- producing countries. Countries highlighted in red in the figure are those excluded from the network, and light blue indicates rough diamond-producing countries. Countries adjacent to rough diamond-producing countries that may have been involved in smuggling or illicit mining before the KPCS were excluded from the network, suggesting that the enforcement of the KPCS has reduced smuggling and illicit trade.

Based on the above results, although the network analysis indicates the possibility that KPCS has reduced smuggling and illicit transactions, the evidence is not strong.

3.2 Effectiveness estimation of KPCS

We estimated the effect of KPCS using DID to provide stronger evidence that KPCS contributed to the reduction in smuggling and illicit trafficking. After propensity score matching, we conducted DID on the average conflict rate for each conflict for the five years before and after KPCS implementation for the treatment and control groups, and estimated that the KPCS intervention reduced the average conflict rate by 7.2% for state conflicts and by 8.8% for non-state conflicts

Figure 1. Countries that have disappeared from the rough gem diamond trade network in Africa after the KPCS

Table 3. DID results for national conflict

	National Conflict		
	Before KPCS (1998-2002)	After KPCS (2003-2007)	diff
Treatment	0.352	0.224	-0.128
Control	0.352	0.296	-0.056
	Difference-in-Difference (DID)		-0.072

Table 4. DID results for non-state conflict

	Non-state Conflict		
	Before KPCS (1998-2002)	After KPCS (2003-2007)	diff
Treatment	0.200	0.104	-0.096
Control	0.240	0.232	-0.008
	Difference-in-Difference (DID)		-0.088

It was estimated that the KPCS intervention reduced the average conflict rate for all types of conflicts.

4. Conclusions

Based on the results of the network analysis and the estimation of the effect of KPCS on conflict using DID, we believe that this study provides empirical evidence to suggest that the implementation of KPCS in 2003 contributed to the reduction of smuggling and the elimination of conflict.

However, the results of this study alone are insufficient in terms of analytical detail and robustness. Due to the limited availability of data, the analysis in this study was conducted on a country-by-country basis, but a smaller granularity is needed for more detailed analysis. In addition, the robustness of the results to fluctuations in the conditional settings and assumptions used in the estimation of the effects of conflict using DID has not been verified.

Although this study concluded that the KPCS is effective in terms of conflict elimination, there are still many issues to be addressed. In particular, countries with diamond deposits tend to be poorer as nations, and their officials have incentives for corruption, making their governance systems more vulnerable. Indeed, illegal mining and smuggling were reported in Sierra Leone after the KPCS (Nina, 2016), and it is assumed that similar situations exist in other rough diamond-producing countries. In addition, the KPCS only covers rough diamonds, polished diamonds are not covered by the KPCS, and the KPCS cannot address a wide range of issues such as human rights violations (Global Witness, 2013). Further efforts need to be made to address these issues in the future.

5. Acknowledgements

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6. References

Gilmore, E., Gleditsch, N.P., Lujala, P. and Rød, J.K. (2005). Conflict Diamonds: A New Dataset. Conflict Management and Peace Science. 22(3): 257–272.

Global Witness (2013). The Kimberley Process. Retrieved from: https://www.globalwitness.org/en/campaigns/conflict-diamonds/kimberley-process/

Lujala, P., Gleditsch, N.P. and Gilmore, E. (2005). A Diamond Curse? Civil War and a Lootable Resource. The Journal of Conflict Resolution. 49(4): 538–562.

Nina, E. (2016). After Blood Diamonds The Moral Economy of Illegality in the Sierra Leonean Diamond Market. MPIfG Discussion Paper 16/9. Retrieved from: https://pure.mpg.de/rest/items/item_2332365/component/file_2346196/content

The Role of V_2O_5 Production in the Lifecycle Impacts of Vanadium Redox Flow Batteries

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1. Introduction

Following the commitments of the Paris Agreement, the European Green Deal has entered into force intending to transform the EU into a climate-neutral continent by 2050, with the intermediate target of reducing the net greenhouse gas (GHG) emissions by at least 55% compared to the 1990 ones, by 2030. To do so, significant changes are required, including a shift to a more sustainable energy system (i.e., energy transition), where renewables are at the cornerstone. Nevertheless, renewables are not constantly available, so supply and demand are not synchronised. Thus, energy storage systems (ESS) are required to guarantee the system flexibility. In this context, it is fundamental to assess ESS's potential environmental impacts along their entire life cycle. In this work, we focus our analysis on the Life Cycle Assessment (LCA) of a particular promising long-duration ESS, which presents a high potential in terms of reuse and recyclability for industrial applications (order of MW): the Vanadium Redox Flow Batteries (VFB).

The main feature of VFB is that the power conversion and storage capacity can be designed separately, guaranteeing a low self-discharge. Indeed, the system is constituted by the external tanks (storage capacity units), containing the vanadium electrolytic aqueous solution (together with H_2SO_4), which is pumped to the cell stacks, where the electrochemical reactions take place (power conversion unit). The membrane allows the H^+ ions to permeate across it. Due to their dimensions, these batteries are suitable mostly for stationary applications. A simplified scheme of the whole battery is shown in Figure 1, and the main reactions that occur on the two sides of the battery are (Puleston *et al*., 2022):

$$\begin{aligned}
&\text{Cathode (+): } VO^{2+} + H_2O \ \square \ VO_2^{+} + 2\,H^{+} + e^{-} \quad E^0 = +1.004\ \text{V}\\
&\text{Anode (-): } V^{3+} + e^{-} + H_2O \ \square \ V^{2+} \quad E^0 = -0.255\ \text{V}\\
&\text{Cell: } VO^{2+} + V^{3+} + H_2O \ \square \ VO_2^{+} + 2\,H^{+} + V^{2+} \quad E^0 = +1.259\ \text{V}
\end{aligned} \qquad [1]$$

The advantages of VFB in relation to other kinds of batteries can be summarised as follows: high scalability, high flexibility, long lifetime (20,000 cycles) and lifespan (20 yr), high round trip efficiency (~75%), no risk of ignition and explosion, reversibility of the reactions that occur in the membrane electrode assembly, and ideally no consumption of ion metals (meaning long-cycle service life) (Louressen et al., 2019). Currently, the main disadvantage of VFB is their high capital cost for deep market penetration (Noack et al., 2016).

Here, we investigate what are the key points and weaknesses highlighted in the literature related to assessing the potential environmental effects of VFB through LCA, being a topic of great interest in the EU, considering that flow batteries will have a dedicated pattern within the *Battery Passport*.

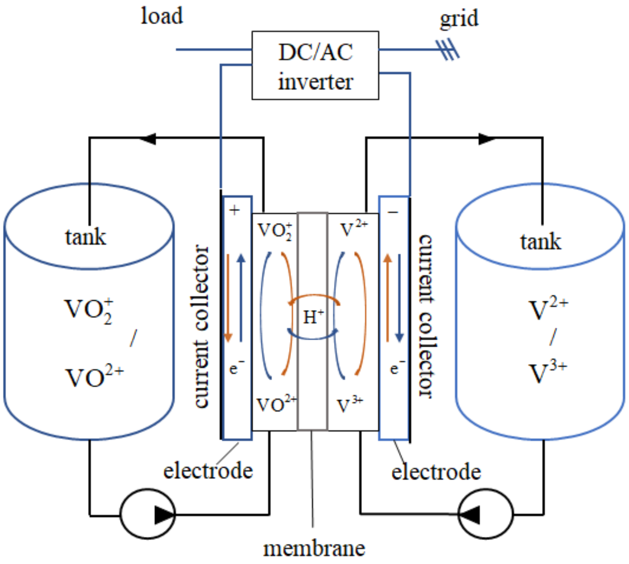

Figure 1. Scheme of a Vanadium Redox Flow Battery, representing both the charging flows (red colour) and the discharging ones (blue colour), and the ion vanadium species involved in the reactions.

2. Materials and Methods

LCA is a standardised methodology (ISO 14000 series) to assess the potential environmental impacts of a product/service encompassing its entire life cycle (cradle-to-cradle or cradle-to-grave model). So, it includes raw materials extraction and processing, transportation, manufacturing, product use phase, and end of life (EoL). It should be pointed out that some products may require the analysis cut at the factory gate (cradle-to-gate approach). LCA methodology is composed of four iterative phases: i. Goal and scope definition (where the main methodological decisions are set, including the definition of system boundaries (SB), functional unit (FU), assumptions, data quality, allocation procedures, and impact assessment methods); ii. Life cycle inventory, LCI, where the energy and material flows are evaluated; iii. Life Cycle Impact Assessment, LCIA, where the magnitude and significance of the potential impacts deriving from the inventory are evaluated; iv. Interpretation of the results (where also sensitivity and uncertainty analysis should be considered). So, the practitioner has many degrees of freedom in developing his LCA analysis.

However, to use LCA as a policy-making tool to set emission thresholds for product families, common rules are needed to develop fair comparisons among products. Thus, the Product Environmental Footprint Category Rules (PEFCRs) have been introduced. In particular, with the *New Batteries Regulation* – Regulation (EU) 2023/1542 the Environmental Footprint (EF) of each battery sold in the EU must be determined and communicated. Thus, PEFCRs for batteries are being launched. However, for flow batteries the rules will be developed soon, meaning that a critical analysis of the LCAs already available for these batteries is crucial to overcoming methodological issues and unfair comparisons.

Thus, we have analysed more than 20 papers related to the LCA of VFB. However, the discussion of the results will be carried out on the bases of the most recent ones, starting from Ref. (Weber et al., 2018), due to their transparent and complete life cycle inventory, which has also been the source for most recent works. On the other hand, works developed before 2018, were mostly based on the inventory of the pioneering work by (Rydh, 1999), which presents a sparse inventory, based on an old VFB design, which is quite different from the ones produced today.

3. Results and Discussion

The analysed papers present different methodological choices, starting from the SB and FU definitions, which in turn depend on the goal & scope of each single study. For this reason, a complete and direct comparison among different studies is not possible. Moreover, few studies (Weber et al, 2018 & Blume et al., 2022) had the opportunity to fully document their bill of materials (BoM) mainly due to the confidentiality of primary data. As concerns the FU, all authors consider the FU as a certain amount of energy stored or delivered by the battery, according to their scope. However, not all the relevant information required for further investigations - with different scopes - has been provided (e.g., stored/delivered energy, efficiency, cycles life, energy/power density, operation time of the battery system, replacement of components, load of the considered coupled system) to have a complete view of the battery under analysis, and to perform further investigations and/or comparisons among different ESS. Distinct SBs were chosen among the available works. Nevertheless, it can be pointed out that to compare these ESS with others, it is necessary to consider the entire life-cycle of the battery (cradle-to-cradle or cradle-to-grave approach) because one of the main advantages is just their EoL: excluding this phase leads to inappropriate and unfair comparisons among different ESS. Indeed, after their (long) service life, the VFB electrolyte can be regenerated and reused without complex and expensive chemical processes, and the battery components can be easily dismantled by using only mechanical power (Blume et al., 2023). All the LCIs of the analysed works subdivide the system into three main subsystems: i. electrolyte, ii. power stack, and iii. auxiliaries. In terms of mass, the electrolyte constitutes almost 90% of the total weight when the building foundation is not considered (more than 40% if the latter is included). The LCIA results with a cradle-to-gate approach highlight that the electrolyte presents the main potential impacts in almost all the impact categories. In particular, the electrolyte and all the related upstream production processes represent more than 95% of the total Acidification Potential (AP), more than 90% of the Global Warming Potential (GWP) and of the Abiotic Depletion Potential (ADP), and more than 50% of Human Toxicity Potential (HTP), while the membrane of the stack affects ~90% of the Ozone Depletion Potential (ODP) (Weber et al., 2018). Furthermore, it should be stressed that the V2O5 concentration in the electrolyte depends on some operative conditions and should not exceed 1.7 M due to solubility issues, e.g., for 1 MWh of provided energy, approximately 148 kgV2O5 m-3 of the total electrolyte solution is needed, with a total volume of 50 m3 of electrolyte (Dieterle et al., 2022). All the aspects related to the V2O5 production process are fundamental because more than 50% of the total impacts of VFB electrolyte depend on the energy consumption for the V2O5 slag processing and on the energy mix of the producing countries. Indeed, the V2O5 is mainly (~88%) derived from titano-magnetite ore slags, which contain only (0.2-2.0)% of V2O5 by weight; it is obtained and processed mainly in China (52%), South Africa (26%) and Russia (19%). Two studies (Weber et al., 2018 & Blume et al., 2022) contain more detailed information on the V2O5 production processes considered, analysing a reference mine in South Africa (from which they have obtained confidential primary data), presenting respectively two different methodological approaches: i) economic allocation at market prices among the main co-products (steel and V2O5 bearing slag); ii) Avoiding allocation (system expansion), by decoupling steel production from the one of V2O5. They have considered all the flows and processes involved in the co-production of steel and V_2O_5, from which they have subtracted the sole production of steel, based on average global data taken from the Ecoinvent database, and the mass balances coming from the coupled processes. Another remarkable aspect that depends on the site of the mines is the ore grade, which in turn affects the total mass balances in the extraction and production chains (Dieterle *et al.*, 2022).

4. Conclusions

In the last decades, many authors have made big efforts and steps forward to develop LCAs of VFB, with the final aim of evaluating the potential environmental impacts of these batteries, and in some cases comparing them to other kinds of ESS. As occurs for all developing technologies, also for VFB there is not a complete inventory that allows us to fully re-elaborate data for other scopes without introducing strong hypotheses, mostly due to data confidentiality. However, from the hotspot analysis available on various works, the electrolyte production (particularly V_2O_5) results the highest contributor for many impact categories, beyond different LCA-related methodological choices. Thus, a next step to deepen the knowledge of the environmental impacts of VRFB, could be to investigate how different V_2O_5 production routes (including alternative or recycling processes) and sites affect the total VFB LCIA, and how methodological choices may influence the overall results, including scenarios for economic allocation being vanadium a critical raw material. These efforts are needed as VFB could be useful where electrification should be boosted, e.g., the mining sector, or where the current energy paradigm must shift, such as energy communities.

5. Acknowledgements

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6. References

Blume, N., Becker, M., Turek, T. and Minke, C. (2022). Life cycle assessment of an industrial-scale vanadium flow battery. Journal of Industrial Ecology. 26: 1796–1808.

Blume, N., Neidhart, M., Mardilovich, P. and Minke, C. (2023). Life cycle assessment of a vanadium flow battery based on manufacturer data. Procedia CIRP. 116: 648–653.

Dieterle, M., Fischer, P., Pons, M.-N., Blume. N., Minke, C. and Bischi, A. (2022). Life Cycle Assessment (LCA): A review of methodological decisions. Sustainable Energy Technologies and Assessments. 53: 102457.

Louressen, K., Williams, J., Ahmadpour, F., Clemmer, R. and Tasnim, S. (2019). Vanadium redox flow batteries: A comprehensive review. Journal of Energy Storage. 25: 100844.

Noack, J., Wietschel, L., Roznyatovskaya, N., Pinkwart, K. and Tübke, J. (2016). Techno-economic modeling and analysis of redox flow battery systems. Energies. 9: 627.

Puleston, T., Clemente, A., Costa-Castellò, R. and Serra, M. (2022). Modelling and Estimation of Vanadium Redox Flow Batteries: A Review. Batteries. 8: 121.

Rydh, C. J. (1999). Environmental assessment of vanadium redox and lead acid batteries for stationary energy storage. Journal of Power Sources. 80: 21–29.

Weber, S., Peters, J. F., Baumann, M. and Weil, M. (2018). Life Cycle Assessment of a Vanadium Redox Flow Battery. Environmental Science & Technology. 52: 10864−10873.

LCA of a Critical Raw Material: State-of-art of Cobalt Production

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1. Introduction

Cobalt is a pivotal raw material for multiple sectors, including the energy, industrial, healthcare, and defence ones, due to its unique chemical-physical properties, i.e., valence properties involving different oxidation states, the highest Curie temperature among the periodic table (1121°C) as a ferromagnetic transition metal, high melting point, high heat resistance and hardness, and high solubility (cobalt powder). These attributes make cobalt essential for a variety of key applications such as battery electrodes, magnets, super-alloys, corrosion-resistant alloys, hard metals, airbags, catalysts, pigments, dyes, etc. On a global scale, it is primarily used in lithium-ion battery (LIB) manufacturing (86% of its global use), thus it is considered one of the key enabler materials for the energy transition. Therefore, its demand is expected to grow from 10 to 20 times by 2030, compared to 2014 values (Deetman et al., 2018).

In nature, cobalt is contained in a wide range of minerals, but its common concentration is too low to allow its economically viable extraction. Thus, it is always extracted as a co-product of other minerals (98% of the total; primary cobalt is only obtained from Co-As ores in Morocco), needing a huge subsequent beneficiation stage (hydrometallurgy, pyrometallurgy, and vapometallurgy are the main extraction routes). Cobalt is mainly obtained as a by-product of copper (60%) and nickel (38%) mining operations, with the Democratic Republic of Congo (DRC) leading on its extraction (73%), followed by Indonesia (5%), Australia (3%), the Philippines (3%), and Cuba (3%). Once cobalt sourcing and processing are carried out, a following refining phase is required for almost all applications. China is the primary refining country (76%), followed by Finland (10%), and Canada (4%) (Cobalt Institute, 2019), meaning that high amounts of processed cobalt are transported across many countries to be refined.

All the points highlighted above have contributed to include cobalt in the European Critical Raw Material (CRM) list, underpinning that: it represents a material with significant importance for the European economy both in economic and strategic terms, and that it presents a high-supply risk. This highlights the need to explore new production routes for cobalt. Furthermore, the expected rise in its demand is amplifying concerns about the impacts of its extraction and production from an environmental and socio-economic standpoint.

In this work, we focus our attention on the published works in literature related to the potential environmental impacts of cobalt production through the Life Cycle Assessment (LCA) tool. The goal is to summarise the current state of research, emphasising key methodological challenges, while also comparing results from different studies and deriving some recommendations for future research.

2. Materials and Methods

The LCA is a standardised (ISO 14000 series) methodology designed to evaluate the potential environmental impacts of the entire life cycle of a product (or service) from the raw materials extraction to the end-of-life (cradle-to-grave). However, for intermediate products that may be used as raw materials in other production chains, e.g., cobalt compounds, the assessments are often limited to the extraction, processing and refining stages (cradle-to-gate approach). The outcomes of such analysis can highlight potential environmental hotspots in raw material production and identify more sustainable production routes by comparing the results of different assessments. However, it is essential to note that meaningful comparisons between LCAs are only possible when the same methodological approach is adopted. This is particularly critical for companion metals (like cobalt), whose LCAs require allocation (meaning the distribution of environmental burdens among different co-products within a multi-output process). In this case, the choice of allocation method significantly impacts results and may hinder comparability between studies.

In this work, a systematic review of the literature on LCAs of cobalt products was conducted by combining studies found in literature alongside datasets from prominent LCA databases (e.g. Ecoinvent). Additionally, studies addressing LCAs of LIBs were included if they modelled in detail the production pathway of cobalt-containing chemical precursors for battery cathodes. The goals of this literature review are to: i) identify the methodological approaches adopted by LCAs practitioners and guidelines for conducting LCAs of cobalt products; ii) compare impact estimations from different sources, pointing out how different production routes, refinery locations, as well as methodological choices, can affect the environmental impact assessment of cobalt production; iii) define benchmarks to enable future comparison of current cobalt production routes with novel emerging ones.

3. Results and Discussion

Despite being an essential component of LIBs and contributing significantly to their environmental impact (Crenna et al., 2021), currently a limited number of LCAs on cobalt products have been developed. Here, we summarise the current state of research, highlighting methodological challenges and potential limitations. Additionally, comparing the findings from different studies allows us to provide suggestions for future research.

As a general note, LCAs of cobalt often exhibit limited geographical representativeness, as they typically assess production routes that do not represent a significant share of global cobalt production. Only Dai et al. (2018) have analysed the main cobalt production pathway. Indeed, their study has frequently served as a data source for the Life Cycle Inventory (LCI) of cobalt sulphate ($CoSO_4$) prior to the integration of corresponding datasets into Ecoinvent (available from v3.7 onwards). All other studies, instead, focused on a particular production route, or, if global, they have omitted refining operations in China, resulting in weak representativeness for cobalt chemicals production, as in the case of the Cobalt Institute's (CI) latest LCA (2019).

Furthermore, despite the efforts undertaken by the mining industry to harmonise the LCAs of metals, the analysed studies often adopted different methodological approaches, particularly regarding allocation (see Table 1). Being cobalt a co-product of different metals, this choice affects the results and might hinder the comparability among studies. As shown in Figure 1, the adoption of an economic allocation approach results in lower environmental impacts compared to mass allocation (see Crenna et al., 2020) when cobalt is obtained as a co-product of non-noble metals (i.e., copper, nickel). Differences in allocation method also explain the significant disparities in Global Warming Potential (GWP) between the CI's latest LCA (2019) and the impacts associated with the latest version of the

Ecoinvent database, which relies on the Cobalt Institute's initial LCA (2015), based on economic allocation. Besides the methodological choices, the results are also affected both by the deposit type and the refining location, as highlighted by the comparison between the studies of Zhang et al. (2020) and Bollwein (2022). Indeed, regardless of analysing similar deposits, the assessment of Zhang et al. (2020) shows significantly higher impacts due to a low cobalt concentration in ores, and the high emission intensity of the Chinese electricity grid.

Table 1. Summary of the selected studies and their specific features.

	Deposit type	Geographical coverage	Allocation approach
Cobalt Institute (2019)	Multiple processing routes analysed	Global, excluding China (no Chinese refineries included)	Mass
Zhang *et al.* (2020)	Ni-Cu-Co	China	Mass
Crenna *et al.* (2021) *based on Dai et al. (2018)*	Cu-Co	DRC (mining and beneficiation) China (refining)	Mass and Economic
Bollwein *et al.* (2022)	Ni-Cu-Co	Canada (mining and beneficiation) Norway (refining)	Economic
Rinne *et al.* (2023)	Au-Co (future potential deposit)	Finland	Economic
Ecoinvent v3.9.1 (2023) *based on Cobalt Institute (2015)*	Multiple processing routes analysed	Global (mining and beneficiation) China (refining)	Economic

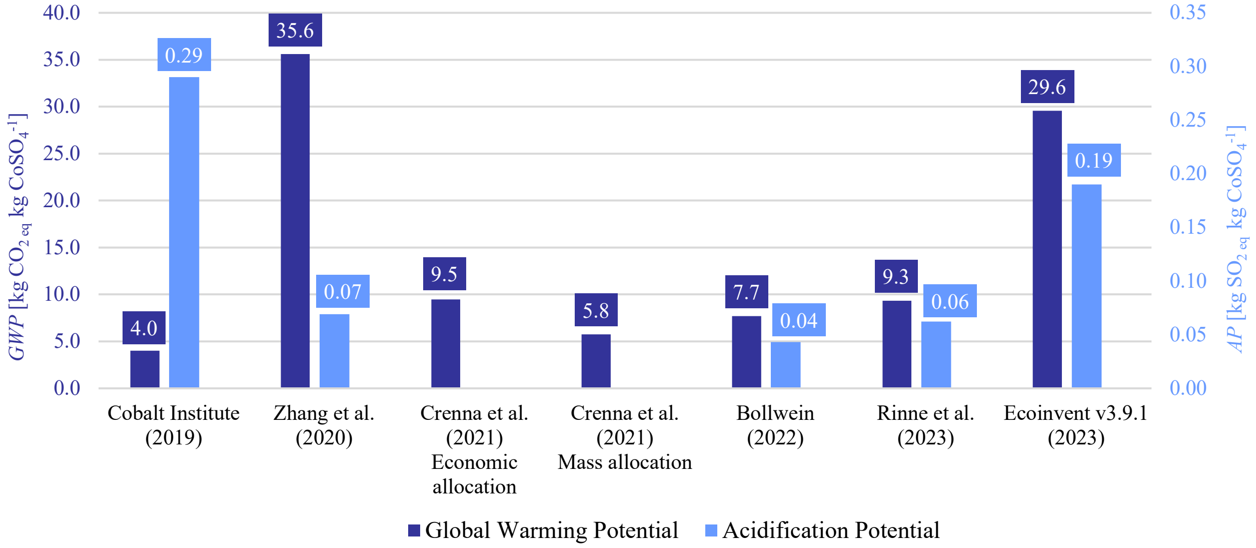

Figure 1. Summary of LCIA results for $CoSO_4$ of selected papers for Global Warming Potential (*GWP*, left axis, dark blue) and Acidification Potential (AP, right axis, light blue) impact categories. Numerical values are reported per kg of produced $CoSO_4$. The *AP* results by Crenna *et al.* (2021) have been omitted being referred to a different unit, which does not allow a direct comparison with the others.

Moreover, insights for future research can be derived from the analysis of existing LCAs of cobalt. Firstly, upcoming LCAs should adhere to industry-recognized guidelines outlined by Santero and Hendry (2016), as occurs in the CF analyses of the major metals associations. Specifically, when cobalt is extracted from copper or nickel, mass allocation based on metal content should be employed. Furthermore, comparisons of future emerging cobalt production routes should preferably be used as benchmarks for current global cobalt production, e.g., the works by Dai *et al.* (2018) and by the Cobalt Institute (2019); these studies represent cobalt refining in China and global production outside of China, respectively, providing a comprehensive basis for comparison.

4. Conclusions

In this work, as a result of a systematic review analysis of the literature on LCAs of cobalt products, we selected representative studies, pointing out how the main choices - strictly related to different processing routes, refinery locations, LCA methodology - can affect the environmental impact assessment of cobalt production. While advocating for a more comprehensive LCA of cobalt, future assessments should also align with sector-specific guidelines. Furthermore, to conduct meaningful comparative analyses and global scale assessments, crucial features are the selection of the most representative processes, geographical sites and suitable sources.

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6. References

Bollwein, M. (2022). Comparative life cycle assessment of prospective battery-grade material production in Norway. Master's Thesis, NTNU. Retrieved from: https://hdl.handle.net/11250/3023809.

Cobalt Institute. (2024). Sustainability; Cobalt Life Cycle Assessment. Retrieved from: https://www.cobaltinstitute.org/sustainability/cobalt-sulphate/

Crenna, E., Gauch, M., Widmer, R., Wäger, P. and Hischier, R. (2021). Towards more flexibility and transparency in life cycle inventories for Lithium-ion batteries. Resources, Conservation and Recycling. 170: 105619.

Dai, Q., Kelly, J.C. and Elgowainy, A. (2018). Cobalt Life Cycle Analysis Update for the GREET® Model. Energy Systems Division Argonne National Laboratory.

Deetman, S., Pauliuk, S., van Vuuren, D. P., van der Voet, E. and Tukker, A. (2018). Scenarios for demand growth of metals in electricity generation technologies, cars, and electronic appliances. Environmental Science & Technology. 52: 4950–4959.

Rinne, M., Elomaa, H. and Lundström, M. (2023). Flowsheet design and environmental impacts of cobalt co-product recovery from complex Au-Co ores. Minerals Engineering. 204: 108444.

Santero, N. and Hendry, J. (2016). Harmonization of LCA methodologies for the metal and mining industry. The International Journal of Life Cycle Assessment. 21(11): 1543–1553.

Wernet, G., Bauer, C., Steubing, B., Reinhard, J., Moreno-Ruiz, E. and Weidema, B. (2016). The Ecoinvent database version 3: overview and methodology. The International Journal of Life Cycle Assessment. 21(9): 1218–1230.

Zhang, T., Bai, Y., Shen, X., Zhai, Y., Ji, C., Ma, X. and Hong, J. (2021). Cradle-to-gate life cycle assessment of cobalt sulfate production derived from a nickel-copper-cobalt mine in China. The International Journal of Life Cycle Assessment. 26: 1198-1210.

Environmental Assessment of Energy Storage Systems and Critical Raw Materials: Life Cycle Assessment of Lithium Production

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1. Introduction

Mineral resources are playing a crucial role in the transition towards green mobility, due to their application in renewable energy and carbon-free technologies (European Commission, 2023a). In particular, lithium holds significant importance for the E-mobility sector and is considered a critical raw material by the EU for the twin energy and ecological transition (European Commission, 2023b). Current EU initiatives and legislations aim to reduce the strain caused by the high lithium demand and ensure its sustainable supply. In Figure 1, the global lithium production is summarised, with the related major producing and processing countries, and the highest shares in final use applications in the global market.

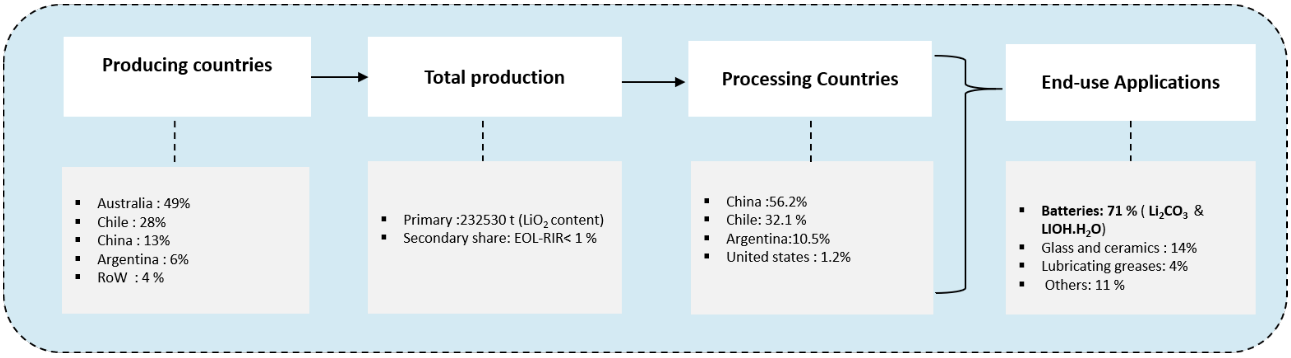

Figure 1. Global production and market overview of lithium, data from (Reichl et al., 2023; European Commission, 2023 & Scrreen2,2023) re-elaborated by the authors, where Eol-RIR: End-of-Life Recycling-Input-Rates, RoW: Rest of the World.

The majority of global lithium extraction (about 97%) comes from spodumene rocks in Australia, from brine sources in the so-called South America's lithium triangle, and from both brine and ore in China (U.S. Geological Survey, 2024; Reichl & Schatz, 2023). In particular, Australian spodumene ore mining has notably increased in recent years, contributing to 49% of global lithium (in terms of Li2O-content) output (Reichl & Schatz, 2023).

However, to meet rising lithium demand, other promising technologies and sources, albeit representing a small fraction of global production, are being explored (Jaskula, 2018). Besides concerns for meeting future lithium demand, further attention has been put on understanding lithium production's environmental impacts. The adoption of Life Cycle Assessment (LCA) has become widespread for understanding these impacts and has proven to be an effective tool for addressing and mitigating potential environmental hotspots associated with each lithium production route.

In this study, we review the existing LCAs of battery-grade lithium production from various sources and production pathways. The aim is to provide a comprehensive assessment on the actual different lithium production routes from both environmental and technological perspectives, as well as to highlight the challenges and limitations of current assessments, aligning with the most recent environmental footprint guidelines within the metals and mining sector.

2. Materials and Methods

The LCA is a standardised methodology (ISO 14000 series) developed to evaluate the potential environmental impacts of the entire life cycle of a product (or service), from the raw materials extraction to the product end-of-life (cradle-to-grave). This approach consists of four steps: (i) defining the goal and scope of the analysis, (ii) composing the related Life Cycle Inventory (LCI), (iii) conducting a Life Cycle Impact Assessment (LCIA), and (iv) interpreting the results (European Union, 2010).

For intermediate products like battery-grade lithium chemicals, this assessment can be also conducted following a cradle-to-gate approach, meaning considering only the extraction, processing and refining stages of the products life cycle. The results of such an assessment can be very useful to identify environmental hotspots in the production of lithium, as well as to identify the most sustainable production routes. Therefore, in this study, we conduct a review of the literature on LCAs of battery-grade lithium production based on the main available production routes following a cradle-to-gate approach. The goal is to compare the environmental impacts of different production routes focusing on the climate change impacts to identify the most environmentally sustainable processes, as well as to understand current environmental hotspots and anticipate future ones.

3. Results and Discussion

Climate change impacts values for each production route are reported in Table 1. In general, the extraction of lithium from continental brines is associated with lower environmental impacts in terms of climate change compared to other production sources considered in this study (Schenker et. al., 2024). Notably, the fabrication and manufacturing stage in the mining cycle generally contributes the most in terms of impacts associated with global warming due to its energy-intensive nature and significant requirement for chemical additives in the process.

Table 1. Climate change contribution impacts related to the production of l kg of Li_2CO_3 of battery grade.

Reference	Type of source	Geological coverage	Production Site	Climate change impacts range range [kg $CO_{2,eq}$ kg^{-1} Li_2CO_3]
Kelly *et al.* (2021); Jiang *et al.* (2020); Ecoinvent	Spodumene ore	Australia China	Greenbushes and Tianqi Lithium	10.6 – 20.4
Schenker *et. al.* (2022);Kelly *et al.*, (2021); Ecoinvent	Continental brine	Chile	Salar de Atacama	2.1 – 3.4
Schenker *et. al.* (2024); Ecoinvent	Geothermal brine	U.S.A.	Salton Sea	17.6– 59.2

The analysis based on the literature background reveals that the major contributions to the production of lithium carbonate from continental brine sources in Salar de Atacama and Salar de Olaroz are derived from the utilisation of sodium carbonate, electricity, and heat (Kelly et al., 2021; Schenker et. al., 2022). This pattern of contribution is consistent with findings in the Ecoinvent databases. In contrast, lithium carbonate (Li2CO3) derived from geothermal brine sources presents its major contribution stemming from the pre-treatment process and the energy consumed during purification and treatment processes. On the contrary, the production of Li2CO3 from spodumene ores is characterised by significant energy consumption, particularly in the leaching process, and the utilisation of sodium hydroxide (Kelly et al., 2021; Jiang et al., 2020).

4. Conclusions

Different configurations matter in terms of environmental performance; each extraction method and processing route reviewed in this study affects the environment differently. There are various mitigation options from technological and ecological perspectives. Significant environmental improvements could be achieved by transitioning to alternative energy sources, integrating circular economy strategies, exploring different chemistry for Li2CO3 recovery, and considering new and low-energy technologies. A handful of factors can induce alterations (e.g. multifunctionality approach adopted) and uncertainties (e.g. data unavailability and assumptions) in the life cycle inventory (LCI) over time and across locations in assessing the environmental impacts of Li2CO3 from the main global production routes considered in this study.

The ore grade or brine composition, site-specific factors (e.g., energy-mix used in the production chain), and other approaches used in the modelling to fill the gaps can continuously change the environment impacts in all production routes considered in this study. Thereby, to reduce such variations and limitations in the inventory stage in order to establish reliable LCA models, multiple scenarios and a hybrid approach, combining a parametric methodology based on simulation modelling with models based on first-hand data can be integrated, considering technological and geographic characterisation to provide deeper insights into these complex alterations.

5. Acknowledgements

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6. References

European Commission, Joint Research Centre. Carrara, S., Bobba, S., Blagoeva, D. (2023). Supply chain analysis and material demand forecast in strategic technologies and sectors in the EU: a foresight study, Publications Office of the European Union. Retrieved from: https://data.europa.eu/doi/10.2760/386650

European Commission, Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs, Grohol, M. and Veeh, C. (2023). Study on the critical raw materials for the EU 2023: final report, Publications Office of the European Union. Retrieved from: https://data.europa.eu/doi/10.2873/725585

European Commission, Joint Research Centre, Institute for Environment and Sustainability. (2010). International Reference Life Cycle Data System (ILCD) Handbook: general guide for life cycle assessment: detailed guidance, Publications Office of the European Union. Retrieved from: https://data.europa.eu/doi/10.2788/38479

Jaskula, B.W. (2018). Lithium, in Mineral Commodity Summaries 2018. US Geological Survey. pp. 108–109. Retrieved from: https://pubs.usgs.gov/periodicals/mcs2018/mcs2018.pdf

Jiang, S., Zhang, L., Li, F., Hua, H., Liu, X., Yuan, Z. and Wu, H. (2020). Environmental impacts of lithium production showing the importance of primary data of upstream process in life-cycle assessment. Journal of Environmental Management. 262: 110253.

Joint Research Centre, Institute for Environment and Sustainability. (2010). International Reference Life Cycle Data System (ILCD) Handbook: general guide for life cycle assessment: detailed guidance. Publications Office of the European Union.

Kelly, J. C., Wang, M., Dai, Q. and Winjobi, O. (2021). Energy, greenhouse gas, and water life cycle analysis of lithium carbonate and lithium hydroxide monohydrate from brine and ore resources and their use in lithium-ion battery cathodes and lithium-ion batteries. Resources, Conservation & Recycling. 174: 105762.

Reichl, C. and Schatz, M. (2023). World Mining Data 2023 - Iron and Ferro-Alloy Metals, Non-Ferrous Metals, Precious Metals, Industrial Minerals, Mineral Fuels. Minerals Production Series, 38, Austrian Federal Ministry of Finance. Retrieved from: https://www.world-mining-data.info/?World_Mining_Data_PDF-Files

Schenker, V., Bayer, P., Oberschelp, C. and Pfister, S. (2024). Is lithium from geothermal brines the sustainable solution for Li-ion batteries? Renewable and Sustainable Energy Reviews. 199: 114456.

Schenker, V., Oberschelp, C. and Pfister, S. (2022). Regionalized life cycle assessment of present and future lithium production for Li-ion batteries. Resources, Conservation and Recycling. 187: 106611.

Scrreen2 (2023). Raw materials factsheets. SCRREEN2 Project. Retrieved from: https://scrreen.eu/wp-content/uploads/2023/03/SCRREEN2_factsheets_LITHIUM.pdf

U.S. Geological Survey (2024). Mineral commodity summaries 2024. USGS Publications Warehouse. Retrieved from: https://pubs.usgs.gov/publication/mcs2024

Global Iron and Steel Decarbonisation Roadmaps: Near-Zero by 2050

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Keywords: Near-zero steel; decarbonisation roadmap; net-zero 2050; iron ore mining; low carbon transition; sustainability gaps.

Abstract

A valuable depth of knowledge has developed in the academic and grey literature as more voices have joined the conversation on decarbonising heavy industry. This paper analyses the current state of research through a critical review of global iron and steel decarbonisation roadmaps to 2050. The consensus among scenarios and modelled pathways is that the sector will achieve near-zero emissions, falling short of net-zero targets by around 10%. The key barriers identified include the availability of recycled scrap, limited availability of high-grade iron ore, de-risking technology investment, uncertain demand and cost gap, the availability, affordability, and reliability of renewable energy and hydrogen, skilled workforce shortages, weak policy signals, and the lack of certification and regulation for fair competition. The roadmaps focus on breakthrough technology pathways for steel producers, while emphasising the need for consistent improvements to yield, energy efficiency, secondary steelmaking, and carbon capture solutions. However, significant sustainability gaps exist in the largely carbon dioxide (CO2) focused plans. Significant doubt prevails for the efficacy of carbon capture and storage, while discussion of indirect emissions from the raw mineral extraction, transport, use, and end-of-life stages of steelmaking are limited. To achieve a just transition, greater attention is needed to address the social licence to operate and broader environmental impacts including the production of waste and non-CO2 emissions. The de-coupling of iron and steelmaking presents an opportunity for strategic international collaboration and shared responsibility in the development of a sustainable iron and steel value chain.

Earth Observation and Sustainable Pursuit of Critical Raw Materials

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Keywords: Critical Raw Materials, Earth Observation, Sustainable Resource Management, EU – Africa corridors

Abstract

Securing a stable supply of critical raw materials (CRMs) is imperative for global sustainability, especially in the pursuit of carbon neutrality by 2050. The European economy, heavily reliant on CRMs imports, actively explores new sources through domestic efforts and international collaborations. As the world shifts away from fossil fuels, sustainable development becomes paramount.

Renewable energies drive a global transition, with CRMs playing a pivotal role in this shift. Despite their scarcity, the presence of CRMs in Earth's subsurface emphasizes the importance of sustainable extraction practices. In 2023, as part of its green and digital transformation, the EU enacted the CRMs Act (European Commission, 2023), setting targets for a secure, diversified, and sustainable supply through domestic extraction, processing, recycling, and import limits by 2030.

Sustainable Resource Management necessitates systematic mapping of mineral deposits, including rare metals, phosphates, and cobalt crucial for decarbonization and global strategic sectors. While progress has been made, the knowledge base still requires improvement. This investigation, framed within the CRMAct, the EU-Africa strategic corridors study (Baranzelli et al., 2022a; 2022b) and the GeoSciencesIR project, emphasizes the necessity for mutually beneficial partnerships. Moreover, this study actively contributes to the ongoing discourse by not only addressing current challenges in CRMs supply security but also by anticipating future needs.

Mining, often in remote locations, poses challenges throughout its lifecycle. Earth Observation emerges as a crucial tool, particularly in inaccessible areas. Bridging geological aspects with future access, this study contributes to the discourse on CRMs supply security and sustainability. As we look to the future, the study serves as a guiding beacon towards a more sustainable and secure CRMs supply chain, essential for the evolving needs of a global, environmentally conscious society.

References

Baranzelli, C., Blengini, G.A., Josa, S.O. and Lavalle, C. (2022a). EU–Africa Strategic Corridors and critical raw materials: two-way approach to regional development and security of supply. Intern. Journal of Mining, Reclamation and Environment. 36: 607–623.

Baranzelli, C., Kucas, A., Kavalov, B., Maistrali, A., Kompil, M., Oliete Josa, S., Parolin, M. and Lavalle, C. (2022b). Identification, characterisation and ranking of Strategic Corridors in Africa. EUR 31069 EN, Publications Office of the European Union, Luxembourg, ISBN 978-92- 76-52430-4.

European Commission (2023). Study on the Critical Raw Materials for the EU 2023 – Final Report.

Prospective Life Cycle Assessment of Emerging Battery Technologies: Silicon-Sulfur and 2BoSS

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1. Introduction

An exponential increase in critical raw materials (CRMs) demand is expected in the coming years, with one of the main drivers of this demand being the batteries to sustain the green energy transition and related green technologies (European Commission, 2023). The dominant technology in the rechargeable battery field is lithium-ion batteries (LIBs), which are heavily dependent indeed on CRMs such as cobalt, lithium, manganese, and graphite. In 2023, about 85% of lithium and 70% of cobalt global demand was for batteries (International Energy Agency, 2024).

Alternative technologies are emerging to improve the energy density of LIBs and reduce reliance on CRMs. One of the most promising of these technologies is the lithium-sulfur battery, because of its high theoretical energy density of about 2600 Wh/kg (Deng et al., 2017). Another field of batteries development to improve LIBs performance regards new anodes, in particular anodes based on silicon. In this context, the ERA-MIN3 project 2BoSS (https://2boss.eu/) aims at reducing the CRMs dependence of the sector and improving the sustainability of supply chains by developing a new battery technology based on a Li2S-based cathode and a silicon-based anode.

Since the aim is to develop a more sustainable alternative, it is essential to evaluate the environmental impacts over the complete life cycle to steer battery development towards minimizing environmental and resource impacts and avoiding burden-shifting. Prospective Life Cycle Assessment (pLCA) is the tool that allows to assess the environmental impacts of a possible future industrial production of the 2BoSS battery. Here, the methodology and challenges of building suitable Life Cycle Inventories (LCIs) collecting data at the laboratory scale are presented, starting with a literature review of lithium-sulfur batteries LCA studies.

2. Materials and Methods

The 2BoSS battery is an emerging technology, currently developed at a laboratory scale (low TRL), so the novel approach of prospective Life Cycle Assessment (pLCA) is considered. pLCA assesses future technological systems and their environmental implications, scaling up emerging technologies using likely scenarios of future performance at full operational scale (Thonemann et al., 2020).

Firstly, a literature review was performed to understand how pLCA have been applied to battery technologies, in particular lithium-sulfur batteries, to identify good practices and evaluate the state of the art. The articles analysed were retrieved on Scopus using the keywords “Lithium-sulfur batter*”, and “LCA”, for a total of 8 studies.

The second part of this study consisted of an extensive analysis of the processes on the laboratory scale and data collection to build a reliable bill of materials for the 2BoSS technology, which could be useful as a starting point for the scaling up of the system and evaluation of future impacts on the industrial scale. The focus was on the electrodes production since it is where the main differences compared to LIBs from a CRMs point of view lie. Lab-scale primary data were collected from laboratory experiments carried out by the project's partners. Data gaps due to lacking foreground data were filled with estimates based on available lab-scale information, such as mass ratios, and secondary data from literature. The production of all the input materials was considered as background data from the Ecoinvent v3 database, except for the active material for the cathode (Li2S) for which a dataset from Keshavarzmohammadian et al. (2018) was selected.

3. Results and Discussion

There are three main challenges of prospective LCA (Thonemann et al., 2020): comparability between emerging and mature technologies, data (availability, quality, and scaling), and uncertainty.

Comparability issues lie mainly in defining functional units, system boundaries, and LCIA methodologies. The methodological choices vary greatly between all the analysed papers, but in general, the two technologies should be compared at the same TRL and at the same point in time. Four out of the five studies which performed a cradle-to-grave analysis considered the electric mobility application, in particular EVs, choosing LIB as the dominant technology (Deng et al., 2017; Cerdas et al., 2018; Wolff et al., 2019; Benveniste et al., 2022). Only Wickerts et al. (2023) performed a cradle-to-grave study selecting a different application than LIBs, i.e. stationary energy storage.

The data availability issue already exists in conventional LCA, but it is exacerbated when dealing with emerging technologies, where often the same sources are cited across multiple studies. Deng et al. (2017), the earliest LCA study analysed, employed the Argonne National Laboratory BatPac software to adapt the values calculated for a Li-ion battery industrial-scale production to a Li-S one. This study is the source of secondary data cited by five of the remaining seven papers. Another important reference results to be Piccinno et al. (2016), cited as the framework used to scale lab-scale chemical production into large-scale by Accardo et al. (2024) and Wickerts et al. (2023). Regarding background data, all articles rely on databases such as Ecoinvent, but the Ecoinvent database does not contain prospective datasets. So, the future evolution of background systems was not modelled in the studies, except for scenario analysis for different energy mixes.

Lastly, the most common way to address uncertainty in the analysed papers is sensitivity analysis through scenarios of parameters variations, such as different cell materials and compositions, energy mixes, and cell energy density.

Table 1 and Table 2 provide the lab-scale inventories of material and energy inputs resulting from the preliminary analysis of electrode production processes, for the anode and cathode respectively. Great attention was put into the analysis of the Silicon Nanowires composite production since it is a newly developed process for which little information is available in literature. One of the main challenges was obtaining data about energy requirements at lab-scale. To fill this gap, literature information from industrial-scale production of LIBs was adapted. Another challenge lies in some of the material inputs not being present in the background database, due to their novelty and specific application. It is the case of SiPh2H2 and Super P for which suitable proxies had to be selected since it was not possible to model the sub-processes with primary data or literature information. Estimations of the uncertainty related to the three main types of inventory data sources (lab-scale primary data, estimates based on lab-scale information, and literature data) are also reported, showing how the lack of primary data could affect the reliability of the subsequent steps of pLCA relying on this inventory.

Table 1. Inventory to produce 1 g of anode.

Input Material	Quantity	Uncertainty	Dataset
Sinw@graphite	0.17 g [2]	±30%	
Graphite	0.14 g [1]	±10%	Graphite, battery grade {GLO}| market for graphite, battery grade | Cut-off, S
SnO_2	0.01 g [1]	±10%	Tin dioxide {GLO}| market for tin dioxide | Cut-off, S
$SiPh_2H_2$	0.84 g [1]	±10%	Silicon tetrahydride {GLO}| silicon hydrochloration | Cut-off, S
Dichloromethane	2.05 g [3]	±200%	Dichloromethane {RER}| market for dichloromethane | Cut-off, S
Electricity	0.003 kWh [3]	±200%	Electricity, medium voltage {ES}| market for electricity, medium voltage | Cut-off, S
Carbon black	0.02 g [2]	±30%	Carbon black {GLO}| market for carbon black | Cut-off, S
Binder (CMC)	0.02 g [2]	±30%	Carboxymethyl cellulose, powder {RER}| carboxymethyl cellulose production, powder | Cut-off, S
Copper collector	0.79 g [1]	±10%	Copper collector foil, for Li-ion battery {GLO}| market for copper collector foil, for Li-ion battery | Cut-off, S
Distilled water	0.01 g [2]	±30%	Water, deionised {Europe without Switzerland}| market for water, deionised | Cut-off, S
Electricity	0.009 kWh [3]	±200%	Electricity, medium voltage {ES}| market for electricity, medium voltage | Cut-off, S
Cooling energy	0.02 MJ [3]	±200%	Cooling energy {GLO}| market for cooling energy | Cut-off, S

1. Lab-scale data; 2. Estimates based on lab-scale data; 3. Adapted industrial-scale literature data

Table 2. Inventory to produce 1 g of cathode.

Input Material	Quantity	Uncertainty	Dataset
Li2S	0.19 g [2]	±30%	Keshavarzmohammadian et al. (2018)
Super P	0.05 g [2]	±30%	Carbon black {GLO}| market for carbon black | Cut-off, S
Binder (PVDF)	0.03 g [2]	±30%	Polyvinylfluoride {GLO}| market for polyvinylfluoride | Cut-off, S
NMP	0.005 g [3]	±200%	N-methyl-2-pyrrolidone {RER}| N-methyl-2-pyrrolidone production | Cut-off, S
Aluminium collector	0.73 g [1]	±10%	Aluminium, wrought alloy {GLO}| market for aluminium, wrought alloy | Cut-off, S + Sheet rolling, aluminium {RER}| sheet rolling, aluminium | Cut-off, S
Electricity	0.006 kWh [3]	±200%	Electricity, medium voltage {ES}| market for electricity, medium voltage | Cut-off, S
Heating energy	0.0005 MJ [3]	±200%	Heat, district or industrial, natural gas {Europe without Switzerland}| market for heat, district or industrial, natural gas | Cut-off, S
Cooling energy	0.02 MJ [3]	±200%	Cooling energy {GLO}| market for cooling energy | Cut-off, S

1. Lab-scale data; 2. Estimates based on lab-scale data; 3. Adapted industrial-scale literature data

4. Conclusions

From the literature review, the importance of building suitable and reliable LCIs at a small scale emerged. When possible, collecting primary data before tackling the scaling up of the system is strongly recommended to improve the data quality and reduce uncertainties. Deng et al. (2017) and Piccinno et al. (2016) were identified as the two main sources of data and scaling framework for pLCA of Li-S batteries.

Building the laboratory scale LCIs for the two electrodes of the battery under study confirmed the difficulties of assessing emerging technologies. A strong collaboration between the LCA experts and the technology developers is required to reduce data gaps and collect reliable and meaningful primary data. Furthermore, the collection process has to be iterative to follow the progress of the technology development. The effort put into building reliable and representative LCIs at lab-scale is fundamental to reducing the uncertainties of the following scale-up step of pLCA, helping obtain meaningful impact assessment results for future industrial production.

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6. References

Accardo, A., Garofalo, A., Dotelli, G. and Spessa, E. (2024). Prospective LCA of Next-Generation cells for electric vehicle applications. IEEE Access. 1.

Arvidsson, R., Janssen, M., Svanström, M., Johansson, P. and Sandén, B.A. (2018). Energy use and climate change improvements of Li/S batteries based on life cycle assessment. Journal of Power Sources. 383: 87–92.

Benveniste, G., Sanchez, A.P., Rallo, H., Corchero, C. and Amante, B. (2022). Comparative life cycle assessment of Li-Sulphur and Li-ion batteries for electric vehicles. Resources, Conservation & Recycling Advances. 15: 200086.

Cerdas, F., Titscher, P., Bognar, N., Schmuch, R., Winter, M., Kwade, A. and Herrmann, C. (2018). Exploring the effect of increased energy density on the environmental impacts of traction batteries: A comparison of energy optimized Lithium-Ion and Lithium-Sulfur batteries for mobility applications. Energies. 11(1): 150.

Deng, Y., Li, J., Li, T., Gao, X. and Yuan, C. (2017). Life cycle assessment of lithium sulfur battery for electric vehicles. Journal of Power Sources. 343: 284–295.

European Commission. (2023). European Critical Raw Materials Act.

International Energy Agency. (2023). Global EV Outlook 2024 Moving towards increased affordability. Retrieved from: https://iea.blob.core.windows.net/assets/a9e3544b-0b12-4e15-b407-65f5c8ce1b5f/GlobalEVOutlook2024.pdf

Keshavarzmohammadian, A., Cook, S.M. and Milford, J.B. (2018). Cradle-to-gate environmental impacts of sulfur-based solid-state lithium batteries for electric vehicle applications. Journal of Cleaner Production. 202: 770–778.

Lopez, S.U., Akizu-Gardoki, O. and Lizundia, E. (2021). Comparative life cycle assessment of high performance lithium-sulfur battery cathodes. Journal of Cleaner Production. 282: 124528.

Piccinno, F., Hischier, R., Seeger, S. and Som, C. (2016). From laboratory to industrial scale: a scale-up framework for chemical processes in life cycle assessment studies. Journal of Cleaner Production. 135: 1085–1097.

Thonemann, N., Schulte, A. and Maga, D. (2020). How to conduct prospective life cycle assessment for emerging Technologies? A systematic review and methodological guidance. Sustainability. 12(3): 1192.

Wickerts, S., Arvidsson, R., Lundmark, S., Svanström, M. and Johansson, P. (2023). Prospective life cycle assessment of Lithium-Sulfur batteries for stationary energy storage. ACS Sustainable Chemistry & Engineering. 11(26): 9553–9563.

Wolff, D., Casals, L.C., Benveniste, G., Corchero, C. and Trilla, L. (2019). The effects of lithium sulfur battery ageing on Second-Life Possibilities and environmental life cycle assessment studies. Energies. 12(12): 2440.

Exploring Social Implications in Emerging Battery Technologies using S-LCA

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1. Introduction

In the ongoing transition to a decarbonized society, mineral resources play a crucial role, with critical raw materials (CRMs) being particularly important (European Commission, 2023). Understanding CRMs involves not only technical aspects but also their societal implications. In this context, the authors present a study that explores the relationship between minerals and society, analyzing the impacts of mining activities on various stakeholders. This study is part of the 2BoSS project, which aims to develop an innovative Li-S battery while prioritizing socially responsible sourcing practices (2BoSS).

A key aspect under scrutiny is the social implications of substituting or reducing reliance on critical raw materials, which is of considerable interest within the field. Following the Social Life Cycle Assessment (S-LCA) methodology and guidelines (Benoit Norris et al., 2020), the study aims to compare the social impacts of conventional batteries available on the market with those of the 2BoSS battery.

The methodology includes an examination of the material composition of both battery types, identifying and assessing the main risks and opportunities arising from the innovation process described. Through this approach, the study illustrates how adopting sustainable mineral management practices can mitigate social impacts and reduce risks for stakeholders. By highlighting the interconnectedness between mineral sourcing, battery production, and societal well-being, the research emphasizes the importance of an integrated approach to resource utilization for a more sustainable future.

2. Materials and Methods

The Social Life Cycle Assessment (S-LCA) adheres to specific methodologies and guidelines, notably the UNEP/SETAC guidelines (Benoit Norris et al., 2020), which serve as a key international reference for developing S-LCAs. These guidelines provide a framework while allowing flexibility in the setting and development of S-LCAs.

For the project's objectives, various materials such as literature related to the social aspects of raw materials mining, reports, scientific papers, and databases from internationally recognized organizations are utilized. One such database is the PSILCA database. In this study, all these materials are employed to compare the social impacts of conventional batteries available on the market with those of the 2BoSS battery. Central to this comparative analysis are the stakeholders involved in the battery production chain, including workers, local communities, value chain actors, consumers, and children, each with their respective subcategories of impacts.

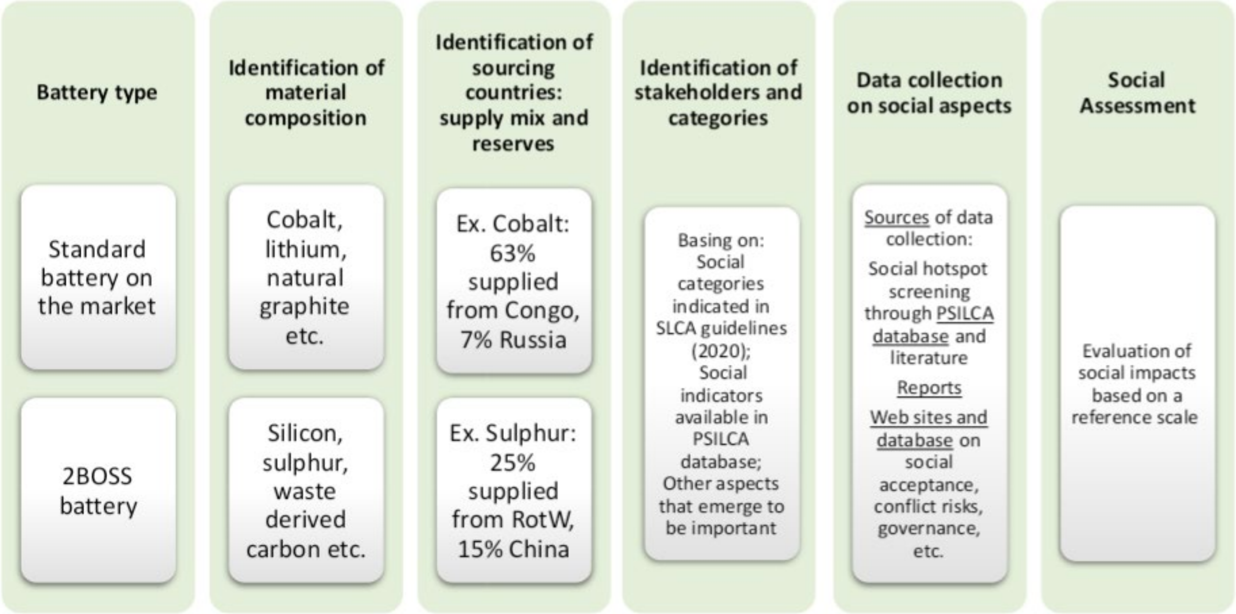

Figure 1. Methodology applied: comparison between two batteries, one standard and one innovative of 2BOSS.

The methodology applied, reported in Figure 1, involves examining the material composition of both battery types, firstly identifying the material composition and then the sourcing countries, identifying the stakeholders' categories and collecting data on various aspects, and conducting a social impact assessment. This phase aims to identify and assess the main risks and opportunities arising from the innovative process and affecting the selected stakeholders. In conclusion, the methodology employed provides a comprehensive understanding of the social impacts associated with battery production, facilitating informed decision-making.

3. Results and Discussion

In the case under study, conducting a Social Life Cycle Assessment (S-LCA) relies heavily on literature analysis and the application of methodology. Field data are not available, so social information must be sourced entirely from secondary data found in databases and literature. The primary reference dataset used is the most updated version of the PSILCA dataset, which integrates information from a multi-regional database with average social aspects data sourced from various references.

Considering the materials involved in the project's case, the battery of 2BoSS differs from the conventional in two main characteristics: the cathode is cobalt-free Li2S, and the anode is graphite-free silicon. These differences entail various social consequences due to the substitution or reduction of critical raw materials (CRMs).

In the context of this study, the collected data is analysed to evaluate how these differences affect stakeholders, communities, and society as a whole. It includes identifying hotspots, areas for improvement, trade-offs, and opportunities for intervention. However, it's also important to evaluate the limitations of the assessment. Some of these limitations are listed below and should be considered when assessing social impacts:

i. Data availability and quality: data may be limited, especially at a regional scale, with transparency and reporting standards varying.

ii. Interactions with environmental and economic aspects: social impacts assessments may overlook synergies or trade-offs between different dimensions of sustainability.
iii. Stakeholder engagement challenges: engaging diverse or marginalized groups can be resource intensive.
iv. Ethical considerations and policy and regulatory context: considerations regarding ethics, as well as policy and regulatory frameworks, need to be carefully addressed to ensure that the assessment process respects the rights of affected communities.

To give readers an example of a material analyzed in the 2BoSS social assessment, let's consider cobalt. As reported in the "This is what we die for" report (Amnesty International, 2016), cobalt is one of the minerals most exported from the Democratic Republic of Congo (DRC). DRC is one of the major exporters globally, and the demand for cobalt is growing at over 5% a year, expected to continue as the lithium-ion battery market expands, particularly with the increasing popularity of electric vehicles. In the DRC, there are significant gaps and weaknesses in the government's regulation of artisanal mining. The Mining Code and Regulations offer limited guidance on health and safety and very few provisions to protect artisanal miners' labor rights. The vast majority of artisanal mining takes place in unauthorized areas, with little to no government regulation on safety and labor conditions. For example, it is estimated that the production of 123,000 hybrid vehicles, on average, is associated with one accidental death in artisanal cobalt mining in the DRC (Nicolas Tsurukawa et al., 2011).

The production of cobalt is associated with risks such as accidents and labor rights violations. However, by developing a battery that does not contain cobalt (and graphite), significant benefits can be achieved from a Social LCA perspective, contributing to the reduction of such risks and promoting sustainable practices in battery production

4. Conclusions

Conducting a Social Life Cycle Assessment of the considered battery at the lab-scale has presented numerous challenges. The analysis required reliance on literature data and the selection of assumptions, leading to unavoidable uncertainties in this type of assessment.

Despite these challenges, the comparison between the two batteries, while adhering to social guidelines and recognizing their limitations, focuses on the stakeholders involved. These stakeholders include workers, local communities, value chain actors, consumers, and children, all of whom are affected by the production of the two batteries. This approach allows for the identification of the main risks and opportunities arising from the innovative process and affecting the selected stakeholders.

5. Acknowledgements

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6. References

2BoSS (2024). Toward sustainable batteries based on silicon, sulfur and bio-mass derived carbon. Retrieved from: https://2boss.eu/

Amnesty International (2016). “This is what we die for” Human rights abuses in the Democratic Republic of the Congo power the global trade in cobalt. Retrieved from: https://www.amnesty.org/en/documents/afr62/3183/2016/en/

Benoit Norris, C., Traverso, M., Neugebauer, S., Ekener, E. Schaubroeck, T., Russo Garrido, S., Berger, M., Valdivia, S., Lehmann, A., Finkbeiner, M. and Arcese, G. (eds.) (2020), Guidelines for Social Life Cycle Assessment of Products and Organizations. United Nations Environment Programme. Retrieved from: https://www.lifecycleinitiative.org/wp-content/uploads/2021/01/Guidelines-for-Social-Life-Cycle-Assessment-of-Products-and-Organizations-2020-22.1.21sml.pdf

European Commission (2023), European Critical Raw Materials Act.

Tsurukawa, N. Prakash, S. and Manhart, A. (2011). Social impacts of artisanal cobalt mining in Katanga, Democratic Republic of Congo. Öko-Institut e.V. Retrieved from: https://www.oeko.de/oekodoc/1294/2011-419-en.pdf

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