



D2.5 – Report on the replication route to other CRM extraction



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Index

Executive Summary	7
1. Introduction	8
2. Methodology	11
2.1 Data pre-processing and questionnaire design	11
2.1.1 Studied mines and their characteristics	12
2.1.2 Technical data collection	15
2.1.3 Sustainability data collection	16
2.2 Development of the MCDA framework	17
2.2.1 MCDA framework basis	18
2.2.2 Weighted Sum Model (WSM)	19
2.3 Structure of the MCDA tool	20
2.3.1 Technical criteria sheet	20
2.3.2 Sustainability criteria sheet	20
2.4 Sensitivity analysis	21
2.5 Final selection process	21
3. Results	23
3.1 Sustainability pillar assessment	23
3.2 Technical feasibility assessment	24
3.3 Sensitivity analysis and model robustness	25
4. Conclusions	24
5. References	26
6. Appendix	28
6.1 Designed questionnaire; sustainability data collection	28
6.2 MCDA; sustainability assessment results	31
6.3 MCDA; technical feasibility assessment results	32
6.4 MCDA final assessment	34

List of figures

Figure 1. Resilex resource recovery treatment train developed by CETAQUA.....	10
Figure 2. Technical, sustainability and overall rankings of the studied Mines A-D	25

List of tables

Table 1. Technical framework for data collection.....	16
Table 2. Sustainability report of Mines A-D through questionnaires and public reports	17
Table 3. Technical feasibility assessment sheet of the developed MCDA.....	20
Table 4. Sustainability assessment worksheet; developed MCDA	21
Table 5. Pillar weights for the MCDA assessment	22
Table 6. Score legend feasibility assessment.....	24
Table 7. Sensitivity analysis result	26
Table 8. Environmental factors of sustainability assessment.....	31
Table 9. Economic factors of sustainability assessment.....	31
Table 10. Social factors of sustainability assessment.....	31
Table 11. Mine A technical feasibility values.....	32
Table 12. Mine B technical feasibility values.....	32
Table 13. Mine C technical feasibility values.....	33
Table 14. Mine D technical feasibility values.....	33
Table 15. MCDA assessment, Mine A.....	34
Table 16. MCDA assessment, Mine B.....	35
Table 17. MCDA assessment, Mine C.....	37
Table 18. MCDA assessment, Mine D.....	38

Acronyms

Ag: silver

AHP: Analytic Hierarchy Process

Al: Aluminium

Cd: Cadmium

Co: Cobalt

CRM: Critical Raw Materials

CSR: Corporate Social Responsibility

Cu: Copper

EIA: Environmental Impact Assessment

ESG: Environment, Social and Governance

ESRS: European Sustainability Reporting Standards

EU: European Union

FE: Iron

g: Gram

GHG: Greenhouse Gases

GRI: Global Reporting Initiative

GVA: Gross Value Added

HRT: Hydraulic Residence Time

ICP-MS: Inductively Coupled Plasma Mass Spectrometry

ISO: International Organization for Standardization

L: Litre

MCDA: Multi Criteria Decision Analysis

MCP: Monitoring and Control Program

MMS: Mining Method Selection

Ni: Nickel

Pb: Lead

pH: potential of Hydrogen

ReSileX: Resilient Enhancement for the Silicon Industry Leveraging the European matrix

TCFD: Task Force on Climate-related Financial Disclosures

TOPSIS: Technique for Order of Preference by Similarity to Ideal Solution

TSF: Tailings Storage Facility

WP: Work Package

WSM: Weighted Sum Model

wt: weight percentage

Zn: Zinc

Executive Summary

This deliverable is part of Work Package 2 ‘Recovery of valuable and critical raw materials in the mining industry’, which aims to develop and validate innovative treatment solutions based on the recovery of critical and valuable raw materials from wastes of the mineral extraction industry.

D2.5 reports specifically on the evaluation of the replication of the Resource Recovery Treatment Train for the recovery of CRM in other mining operations, geographical context and sectors where the treatment train can be applied.

In this regard, a Multi-Criteria Decision Analysis (MCDA) was employed as a structured and transparent methodology to integrate diverse technical and sustainability data points for the assessment of potential replication sites. By assigning specific weights to technical feasibility (0.35) and sustainability pillars (0.65), the model identifies the site with the highest potential for operational success and social acceptance. The assessment evaluated four distinct European mine sites; Mines A, B, C, and D with a combination of mineral processing capabilities, hydraulic flow volumes, and organizational policy maturity, allowing for a rigorous test of the technology's adaptability across different operational mines.

Finally, Mine A identified as the best candidate for technology replication due to highest degree of technical adaptation and a very good sustainability profile. A sensitivity analysis confirmed the robustness of the site selection model, demonstrating that the final rankings remained stable even under 10% variations in pillar weighting.

Although all sites meet baseline EU requirements, the assessment highlights clear pathways for standardizing sustainability reporting such as European Sustainability Reporting Standards (ESRS) and Global Reporting Initiative (GRI).

1. Introduction

Replicating a treatment train from pilot scale to an operational mine works requires solid and evidence-based decision-making framework which considers both site-specific technical characteristics and sustainability factors (Opitz et al., 2022; Binnemans & Jones, 2023; Erakca et al., 2024).

In mining field, the compatibility of the feedstock (i.e. ore mineralogy, metal concentrations, and liquid stream) determines the technical feasibility of a treatment process (Yu et al., 2023; Ramos et al., 2024). At the same time, environmental, economic and social aspects determine whether replication is acceptable, responsible and feasible within the broader context of a sustainable circular economy (Jovanović et al., 2023; Butnar et al., 2024).

Selecting the best candidate for replication requires an integrative decision framework that can combine heterogeneous, often qualitative information into a transparent, auditable ranking. Multi-Criteria Decision Analysis (MCDA) is widely recognised as an effective approach for this class of problems due to capability to handle multiple objectives, support a structured weighting of priorities, and facilitate sensitivity testing of the final ranking (Cinelli et al., 2020; Abdullah et al., 2021; Bousquet et al., 2023).

MCDA has also proven as a well-established method to address multi-dimensional, multi-stakeholder problems (Huang et al., 2011; Wang et al., 2024). In environmental and resource management fields, MCDA provides a framework to compare alternatives such as sites, technologies and remediation options across a wide range of criteria considering preferences and weights (Zolfani et al., 2018; Ziemba., 2022).

In the context of mining, MCDA has been used in a variety of applications for instance sustainability assessments and remediation prioritizations of mines. As an example, a comprehensive review of MCDA applications to mining method selection (MMS) found that many studies adopt methods such as the Analytic Hierarchy Process (AHP), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), or fuzzy extensions of these, combining geological, economic and environmental criteria (Ma et al., 2022). The literature highlights a trend toward more systematic, data-driven, multi-criteria methods (Ma et al., 2022). Similarly, a survey conducted by industry practitioners concluded that MCDA is particularly useful in mine planning and related decisions where multiple objectives, stakeholders and uncertainties do exist (Mahase et al., 2016).

MCDA has also proven valuable for site selection and sustainability evaluation in mining and contaminated-site remediation contexts. Recent work illustrates how integrated MCDA frameworks combining environmental, social, and economic indicators, can rank mining areas or rehabilitation strategies, and support sustainable

decision making (Yu et al., 2025; Li et al., 2024). These studies demonstrate the flexibility of MCDA in handling both quantitative metrics (e.g., emissions, water usage, cost) and qualitative narratives (e.g., community acceptance, social licence). These studies also underline the importance of sensitivity analysis to test the stability of rankings under changing weights or uncertainty (Floris Abrams et al., 2024; Li et al., 2024).

On the methodological side, there are some challenges conducting MCDA. These include subjectivity in weight assignment, the need for careful normalization of heterogeneous criteria, and the potential influence of data gaps especially social or long-term environmental impacts (Wang et al., 2024). To address these issues, the literature suggests documentation of criteria, normalization rules consistent with physical realities, and sensitivity testing (Wątróbski et al., 2019).

Considering this information, MCDA conducted by Weighted Sum Model (WSM) and complemented by sensitivity analysis, considered as a widely accepted approach for selecting the best candidate mine for replication. It allows a structured comparison of candidate sites across technical and sustainability dimensions, produces a ranked list based on priorities, and enables transparent exploration of how sensitive results are for data uncertainties. This methodology aligns with the emerging best practices in both mining and environmental decision-making literature.

Priore to this task, and in relevant activities of WP2, the characterisation of wastes from the mineral extraction sector and associated industrial by-products was carried out collaboratively by CETAQUA and THARSIS MINING. In this framework, CETAQUA focused on the analysis of acidic water streams, while THARSIS MINING undertook the characterisation of solid waste materials originating from mine waste deposits in Europe.

To recover CRM as efficiently as possible, the Resilex treatment train was developed by CETAQUA in eight different units, as shown in Figure 1. The target metals present in the acid wastewater were removed in three different units: physico-chemical (Fe and Al), sulphide precipitation (Cu and Zn) and evaporator-crystalliser (Co, Ni). The treatment was conducted in multiple steps based on chemical properties and solubilities of the metal ions. Since each metal has a pH range and a mineral phase to precipitate effectively, sequential selective precipitation ensures a more complete and efficient removal. The initial mass balance calculations for the proposed treatment train demonstrate significant potential for metal up-concentration and resource recovery. Under a zero-loss scenario, Copper (Cu) and Zinc (Zn) concentrations can be increased by a factor of seven, yielding 0.31 g/l and 1.72g/l in the slurry in the form of sulphides, and no losses in the treatment train. Similarly, Co, Ni could be concentrated by more than 50,000-fold, with Co precipitating predominantly as sulphates and Ni reaching a concentration of approximately 94 g/L in the residual brine. Sulphuric acid

at concentrations exceeding 50% (w/w) could be generated from solid wastes via thermal oxidation, followed by downstream sulphuric acid production units.

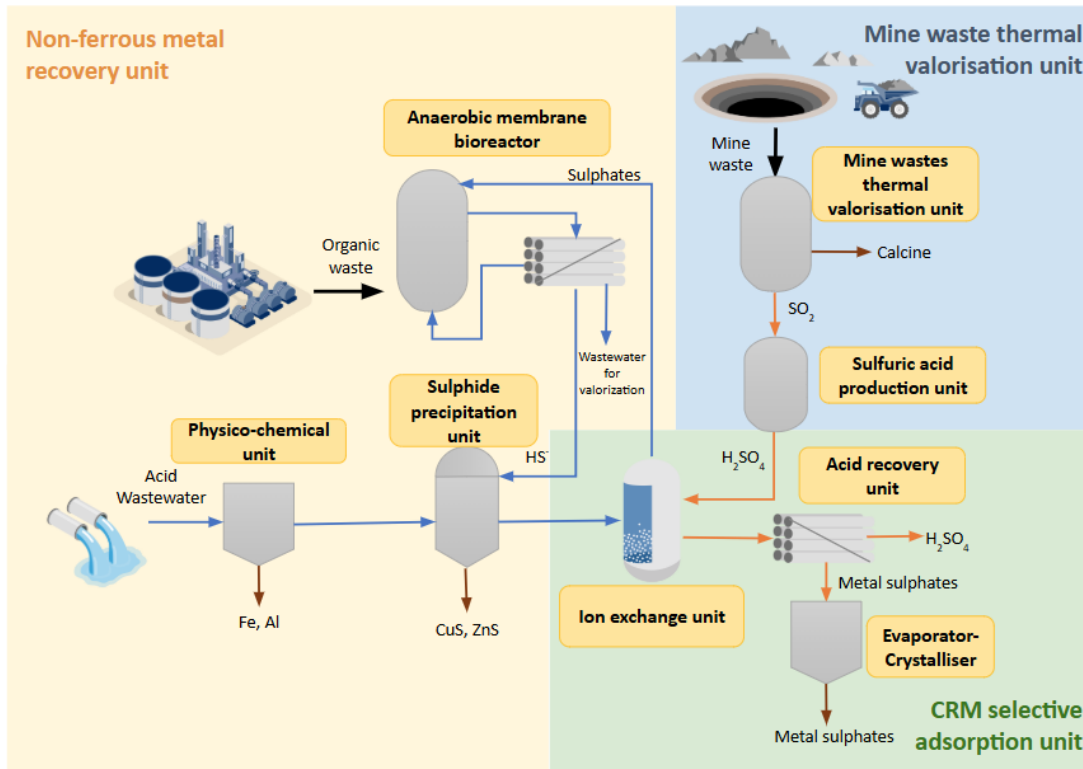


Figure 1. Resilex resource recovery treatment train developed by CETAQUA

The objective of this task is to evaluate the potential replication of the Resource Recovery Treatment Train for the recovery of Critical Raw Materials (CRM) in other mining operations, geographical contexts, and industrial sectors where its application could be viable. The replication study involves a comprehensive assessment from technical, economic, environmental and social perspectives.

2. Methodology

The methodological framework was developed to identify the most suitable mine site for the replication of the Resilex treatment train for ore processing and metal recovery. As mentioned in the Introduction section, the treatment train has been tested at pilot scale by CETAQUA using a set of representative ores and organic wastewater.

In order to assess the replication candidates, it is essential to evaluate potential mines based on

- (i) Compatibility of their technical conditions with the Resilex treatment train
- (ii) Companies' performance across environmental, economic and social sustainability parameters

To achieve a transparent and evidence-based selection, a Multi-Criteria Decision Analysis framework was developed. The framework integrates quantitative technical indicators with qualitative sustainability data, to produce a structured and quantitative-based ranking of candidate sites. The MCDA framework ensures that decisions reflect both the operational feasibility of the technology and the sustainability ambitions of the project, in alignment with EU principles i.e. Green Deal, Circular Economy Action Plan, and Responsible Raw Materials Extraction.

The Methodology section describes the studied mines, the data sources, evaluation criteria, scoring procedures, weighting approaches, and sensitivity analysis incorporated into the MCDA tool.

2.1 Data pre-processing and questionnaire design

The task started with a careful monitoring into a database provided by the WP2 partner ICAMCYL, in which key information on several mining sites across Europe was provided. This database included details such as the substances of interest, ore types, permit status, operator or ownership, and geographical location. The data were obtained through an in-depth review of European geological and mining portals, including the Spanish Mining Cadastre (Catastro Minero Español).

The database was shared with WP2 partners to identify mining projects aligned with the Resilex objectives, particularly those with similar processes and target substances for recovery. It was later verified with ICAMCYL which sites were active and held valid exploitation permits lead to the initial list of potential mining sites. The list includes preliminary information on location, extracted metals, and regulatory status and was subsequently refined to define a shortlist of priority sites for replication; a number of six mines.

A semi-structured questionnaire was developed to collect harmonised technical and sustainability-related information from the six shortlisted mining companies. The questionnaire design (Appendix 6.1) followed several iterative drafting rounds among project partners, ensuring that the questions satisfy treatment train evaluation and the subsequent MCDA analysis. The questionnaire was divided into two major sections (technical and sustainability) to capture information essential for assessing replication potential. Once finalised, the questionnaire was distributed to the shortlisted mines to maximize response quality. Each mine first received a formal communication outlining the project's objectives, the purpose of the questionnaire, and the importance of their participation in the replication assessment. This initial conversation included a clear explanation of how the collected data would be used, along with reassurance regarding confidentiality and compliance with data protection requirements. From the initial six mines, two gradually ceased communication and were subsequently eliminated from the assessment. For the remaining four mines, wherever data provided in the questionnaires was insufficient, public sustainability and policy reports were retrieved from company websites to complete the analysis.

2.1.1 Studied mines and their characteristics

In this section, the four final mines selected to conduct the replication exercise are introduced together with information collected regarding their technical readiness, feedstock characteristics, and robust sustainability and governance frameworks. Due to the agreement made with mines in the first outreach their names and identifiable information are excluded from the report.

Mine A

Mine A is a key industrial operation located in Southwestern Spain. Its primary activity involves the production of high-value metals derived from the processing of mixed copper and zinc sulphide concentrates. This existing industrial infrastructure and its proven capability in managing polymetallic sulphide concentrates make it a highly relevant target for the Resilex treatment train. The site's current focus on mixed copper and zinc sulphide concentrates suggests that the residual streams (e.g., tailings) are likely rich in the target valuable compounds being pursued by the replication task. Furthermore, Mine A exhibits an exemplary and comprehensive commitment to Corporate Social Responsibility (CSR) and Environmental, Social, and Governance (ESG) standards, making it an ideal option for Resilex objective on sustainable resource management. Regarding environmental impacts, the site operates an environmental management system certified to the ISO 14001:2015 standard, demonstrating a preventative and continuous improvement approach to environmental performance, and uses the recommendations of the Task Force on Climate-related Financial Disclosures (TCFD), presenting commitment to climate change mitigation and

transparent reporting. Within the site, water usage is highly efficient, with a strict policy prioritising the re-use and recirculation of water. Process water from the Tailings Storage Facility (TSF) supernatant is continuously pumped back into the processing plant, resulting in a significant reduction in external water supply needs. This robust water cycle is critical for integrating new hydrometallurgical or recycling processes.

On socio-economic impact, Mine A is a significant pillar of the regional economy, contributing 2.9% of the host province's Gross Value Added (GVA) and accounting for 1.2% of total employment. It also implements local agreements to promote direct and indirect employment.

Mine B

Mine B is situated in Southwestern Spain, reinforcing the regional cluster of polymetallic sulphide operations. This site has a significant recent investment of more than €300 million into a polymetallic deposit containing substantial reserves of zinc, copper, lead, and silver. The co-occurrence of base metals (Zn, Cu, Pb) and a precious metal (Ag) is expected to translate into complex metal-bearing wastewaters requiring treatment, thereby providing a suitable matrix for replication of the Resilex treatment train.

Mine B demonstrates a clear commitment to integrating circular economy principles and robust social engagement from the inception of its operations, validated by its certification for compliance with international best practices in environmental, social responsibility, and corporate governance (ESG).

Considering environmental performance, a cornerstone of the site's environmental plan is the high degree of waste integration and backfilling. More than 50% of the generated waste is planned for reintroduction into the mining voids, significantly reducing the surface footprint and long-term liability associated with conventional waste disposal. The site implements a closed-loop system where all water used in the operation will be treated for reuse, minimising external water reliance and environmental discharge risks. The environmental restoration plan includes a robust commitment to land redevelopment, soil restoration, and reforestation with native species. Crucially, the plan actively provides support to the nearby river, ensuring minimal impact on local hydrology and ecosystems.

Considering socio-economic impact, the mine project is a major source of regional employment, with an expectation to generate more than 1,000 direct and indirect jobs over its lifespan. The mine company also aims to support for adapted agriculture, and improvement of public spaces to ensure the economic benefits extend beyond the current mining activities.

Mine C

Mine C is situated in Southern Spain, operating an open pit mine complex. Critically, the site includes a co-located hydrometallurgical processing plant. The current open pit mine boasts a high copper grade, typically between 5% and 6% per tonne of mineral. While this high-grade resource minimises the volume of waste per unit of copper produced, the co-located hydrometallurgical process streams present immediate, high-concentration opportunities for the extraction of valuable compounds. Beneath the current deposit, a significant reserve of primary sulphides of copper, zinc, silver, and lead has been identified. This future resource ensures the long-term relevance of the site for advanced polymetallic processing technologies and shows some potential for the Resilex treatment train replication task.

Regarding the environmental performance, the site has a formal Monitoring and Control Program (MCP) to track and regulate various environmental impacts. This process ensures the continuous assessment of predicted environmental effects, as outlined in the initial Environmental Impact Assessment (EIA), providing crucial, verifiable data on the environmental performance of both the existing and the new (replicated) processes.

As for socio-economic impacts, the company maintains a policy of continuous dialogue with nearby neighbours and stakeholders, actively supporting their needs and priorities. This established social license to operate is vital for the smooth deployment of new industrial technologies. The mine actively seeks to foster local business opportunities, aligning with the EU objective of promoting regional economic resilience and value creation. The company paramount measures for the health and safety of all personnel working on site or in off-site activities

Mine D

Mine D is located in Southwestern Spain, and its operation focuses on the extraction of copper, a metal of great importance for the energy transition and electrification technologies within the European Union. The site's strategic ambition is directly aligned with EU policy objectives, aiming to maximise production to support global decarbonisation and electrification. Copper is a critical component for renewable energy infrastructure (wind turbines, solar power), electric vehicles, and transmission grids. Resilex treatment train's replication at this site can potentially provide a direct pathway to increase the resource efficiency and security of the EU's Copper supply chain. Mine D stands out for its ambitious, measurable environmental and social commitments.

Considering environmental impacts, the company has set a firm target to achieve net zero emissions by 2050, which is fully consistent with the overarching goal of the European Green Deal. The site treats water as a precious resource and uses a

catchment-based approach to managing surface and groundwater. This water management policy is vital for integrating new hydrometallurgical or resource recovery processes, ensuring that the treatment train operates with maximum water efficiency and minimal impact on the local hydrological system. The company also target to source 50% of its all used electricity sources from renewable sources by 2050.

Considering socio-economic impacts, the site is committed to ensuring stakeholders are appropriately informed and engaged with the companies' activities. This commitment, coupled with efforts to recognise and respect the cultural heritage of host communities and indigenous people, provides a strong basis for achieving the necessary social license to operate for new process deployment. The mine generates economic benefits through local procurement, employment, and tax contributions. The company also set target policy on zero fatalities and prevention of serious on-site incidents

2.1.2 Technical data collection

The technical data collection aimed to compile the physicochemical and operational parameters required to assess whether Resilex treatment train could operate effectively under site-specific conditions at the candidate mines. Since the treatment train is bounded by a physicochemical operating window defined during batch and pilot-scale conditions validation, the data collection focused on characterising the average conditions within the mining waste and wastewater processing system. This approach allows for a realistic assessment of operational compatibility, rather than an idealised comparison based on nominal values only.

Key technical parameters collected included:

- Target compound concentration ranges: This encompasses the concentration of main focused metals (Cu, Zn, Ni and Co) and valuable metals within the primary ores, process water, and secondary waste streams. These data are fundamental for determining the potential economic yield and validating the required mass-balance for the treatment train.
- Process water volume and flow rate: These metrics are essential for establishing the required system capacity and designing the necessary hydraulic residence time (HRT) for the treatment train to achieve target recovery efficiencies.
- pH range and variability: pH is the most critical operational parameter for many hydrometallurgical and physiochemical separation processes. Knowledge of its range and buffering capacity can decide the necessary reagent dosing strategy (e.g., acid or base consumption) and prevents potential operational failures, such as precipitation or re-solubilisation of target compounds.

- Sulphur concentration (wt%): High sulphur content in mining wastes is indicative of the mineralogy (sulphide-rich) and has direct implications for potential acid generation
- Waste volume and characteristics: Understanding the total volume of solid wastes and its composition is necessary to size the input capacity of the treatment train and calculate the overall reduction in environmental burden achieved by the project.

Due to the absence of physical waste samplings for Mine A and Mine B, parameters within the solid waste category were excluded from their specific evaluation matrices. For Mines A and B, the weights originally assigned to the solid waste parameters were redistributed proportionally across the remaining technical sub-criteria. This normalization process ensured that the final ranking remained mathematically consistent and that the MCDA results reflect only the verified data available for all candidates.

Candidate mine sites whose operational conditions are closer to Resilix treatment train are therefore expected to require minimal adaptation of the treatment configuration and operating conditions, resulting in a higher likelihood of successful replication. Conversely, significant deviations from these ranges may necessitate targeted process adjustments or pre-treatment steps.

The technical framework for data collection is presented in Tabel 1.

Table 1. Technical framework for data collection

Category	Parameter
Liquid stream	Cu metal concentration
Liquid stream	Co metal concentration
Liquid stream	Ni metal concentration
Liquid stream	Zn metal concentration
Liquid stream	Other valuable metals concentration
Liquid stream	Water flow rate
Liquid stream	pH range
Solid waste	Sulphur concentration (wt%)
Solid waste	Waste volume (quantity)

2.1.3 Sustainability data collection

Sustainability information was extracted from both the designed questionnaires and publicly available corporate sustainability reports, ensuring a comprehensive view of each mine's environmental, social, and economic performance. This holistic data collection is essential for assessing the non-technical feasibility of the replication and confirming the sites' commitment to the EU Green Deal objectives.

The environmental assessment focused on critical areas of resource management and impact mitigation, aiming to identify sites with better performance in environmental responsibility. The social and economic components, on the other hand examined how each operation ensures the well-being of its workforce and acts as a positive force for regional development. A summary on sustainability performance of the four Mines and some recognized gaps is presented in Table 2.

Table 2. Sustainability report of Mines A-D through questionnaires and public reports

Mine	Environmental Pillar	Economic Pillar	Social Pillar
Mine A	ISO 14001; TCFD climate risk integration; verified carbon footprint; 10–15% fresh water use via thickening systems	2.9% contribution to provincial GVA; high priority on local procurement and subcontracting.	historical heritage protection; standard health and safety protocols.
Mine B	Standard legal environmental monitoring; water recovery from tailings; lack of ISO 14001 certification.	Standard regional economic role; lower performance in local procurement compared to Mine A.	Land re-development projects; general community engagement.
Mine C	Focused on metal recycling via co-located hydromet plant; information gaps in climate risk/GHG reporting.	High industrial value-add through secondary metal processing and recycling circuits.	Access to sanitation initiatives; health-education programs; moderate safety reporting, on-site personnel health and safety
Mine D	Explicit "Net Zero 2050" goal; quantitative targets for GHG reduction; general water management policy, plan to use renewable sources	Standard GVA contribution; focus on regional employment stability.	Leading scores in Human Rights policies; comprehensive community well-being and health programs. Plan to reduce on-site accidents

2.2 Development of the MCDA framework

As discussed in the Introduction section and based on recent literature (Lourenço et al. 2022; Pouresmaeli et al. 2024), MCDA offers the most structured and scientifically defensible approach, due to the following characteristics:

- I. Integration of heterogeneous data: In this exercise, MCDA integrates diverse data types, including quantitative technical measurements (e.g., flow rates) and qualitative sustainability assessments (e.g., governance commitments).
- II. Transparent weight elicitation: MCDA allows for the explicit and transparent weighting of criteria, ensuring that the final ranking accurately reflects the project's strategic priorities

- III. Replicability and bias reduction: It establishes clear utility functions and scoring rules, providing replicable site scoring and ranking while explicitly reducing subjective bias
- IV. Sensitivity testing capability: The framework supports sensitivity analysis, which is essential for understanding the robustness of the final site selection to potential changes in assumptions or criterion weights.

2.2.1 MCDA framework basis

It is of upmost important to standardise the collected raw data and translate it into a unified, format compatible with the quantitative structure of the MCDA Decision Matrix.

A. Technical Data Normalisation

The technical dataset, comprising numerical values such as pH levels and metal concentration ranges, was converted and normalised to a 0–1 comparability scale (where 0 indicates minimum compatibility and 1 indicates maximum compatibility). Normalisation rules were developed such that mines whose conditions (e.g., pH, variability, sulphur concentration) closely matched the treatment train's optimum ranges received scores closer to 1.

B. Sustainability Data Quantification

Sustainability data, which were qualitative in nature were processed using a structured scoring rubric. We translated narrative responses into semi-quantitative values, typically on a 1–5 scale, which were then normalised to the MCDA's 0–1 scale (where 0 represents very poor sustainability performance and 1 represents excellent performance). The conversion followed clearly defined descriptors to ensure consistency across all mines. For example, certification to ISO 14001 (Mine A) scored significantly higher than a general statement on environmental care.

Once all individual criteria were objectively scored and normalized, the process proceeded to assigning weight to reflect the relative importance of each factor to overall project success as below:

- Technical Criticality: Technical parameters received weights based on their importance for the treatment train functionality. For example, the pH stability and the concentration of the target valuable compound were assigned higher weights than less critical parameters like the total waste volume.
- Strategic Alignment: The three sustainability pillars—Environmental, Social, and Economic were assigned weights that reflected the project's broader strategic alignment with Horizon Europe's sustainability and circular economy commitments. Sub-criteria within each pillar (e.g., water management vs. land use) were assigned proportional weights, either equally distributed

Finally, all normalized and weighted data were compiled into a structured, worksheet dataset formed the MCDA analytical tool. Subsequent quality assurance checks were performed to verify internal consistency and ensure that the chosen aggregation functions (weighted sum) produced meaningful, reproducible comparisons for the final ranking and selection of replication sites.

2.2.2 Weighted Sum Model (WSM)

The Weighted Sum Model (WSM), one of the most widely accepted and transparent methods in MCDA, was selected as the core aggregation technique for ranking the candidate mine sites.

WSM is particularly appropriate for this replication study given the following fundamental assumptions regarding the decision problem:

- Meaningful normalisation: All heterogeneous criteria, from qualitative sustainability scores to quantitative technical metrics were normalised onto a common, non-dimensional scale (e.g. 0-1)
- Criteria independence: The performance score of a site on one criterion (e.g., pH) is reasonably independent of its performance on another (e.g., community engagement), presenting the additive property of the model.
- Transparent linear aggregation: The ultimate decision is based on a clear, linear, and easily interpretable method for aggregating performance, ensuring the ranking is fully traceable back to the individual criteria weights and scores.

Under the WSM framework, each mining site receives a final score that is the sum of the product of the normalised score for each criterion and the weight assigned to that criterion. The final aggregated score for site j is calculated as:

$$S_j = \sum_{i=1}^n w_i x_{ij} \quad \text{Equation 1}$$

Where:

- S_j = The final aggregated score for candidate site j .
- w_i = The weight of criterion i , reflecting its relative importance to project success (where $\sum_{i=1}^n w_i = 1$)
- x_{ij} = The normalised score of candidate site j with respect to criterion i (on the 0-1 scale).
- n = The total number of criteria used in the decision matrix.

2.3 Structure of the MCDA tool

As explained in the previous section, the MCDA tool was implemented as a multi-sheet Excel model where it contains the following components:

2.3.1 Technical criteria sheet

This sheet contains the quantitative criteria used to evaluate technical compatibility with the treatment train. Each criterion is:

- Normalized to a 0–1 scale
- Assigned a weight based on expert judgements from CETAQUA and THARSIS Mining
- Multiplied by the weight to obtain a weighted contribution

The technical feasibility tool is presented in Table 3.

Table 3. Technical feasibility assessment sheet of the developed MCDA

Category	Parameter	Weight	Score (0-1)	Weighted Score
Liquid stream	Cu metal concentration			
Liquid stream	Co metal concentration			
Liquid stream	Ni metal concentration			
Liquid stream	Zn metal concentration			
Liquid stream	Other valuable metals concentration			
Liquid stream	Water volume			
Liquid stream	pH range			
Solid waste	Sulphur concentration (wt%)			
Solid waste	Waste volume (quantity)			

“Weight” represents the importance of each parameter in technical feasibility assessment, “score” reflects the closeness of each parameter value to the one measured in Resilex Treatment Train, and the “weighted score” is the combination of parameter importance and its closeness and is the multiplication of the last two criteria calculated for each row, later used in the final MCDA assessment.

2.3.2 Sustainability criteria sheet

The sustainability worksheet contains sustainability criteria collected by the questionnaire and from companies reports where converted to numerical values. The worksheet is presented in Table 4.

Table 4. Sustainability assessment worksheet; developed MCDA

Pillar	Pillar Weight (0-1)	Sub-criterion	Sub-weight	Score	Weighted Sub-score	Pillar Total	Pillar Weighted

Pillar weights are decided as explained in Table4, the sub-criterion represents each indicator of a pillar (such as water efficiency in environmental pillar). Sub-weights show the importance of each criterion within the pillar which assumed equal for all indicators. The score decides how well the companies perform for any of the indicators. The weighted sub-score shows the importance of each criterion within its own pillar and is a multiplication of score to sub-weights. Pillar total is the summation of all weighted sub-scores within one pillar shows the final performance of Mines in one pillar. Finally, Pillar total represents the score of one mine within any of the pillars for final assessment and is a multiplication of pillar total to the pillar weights.

2.4 Sensitivity analysis

To assess the robustness of the ranking and the primary pillar weights values assigned to each pillar of technical, environmental, economic and social, a dedicated Sensitivity sheet was developed.

For each pillar weight, two alternative scenarios were computed:

- –10% of pilar weight
- +10% weight increase of pilar weight

These adjustments test whether small changes in the pillar weight importance significantly alter site ranking.

For each scenario:

$$\text{New Weight}_j = \frac{\text{Original Weight}_j \times (1 \pm 0.10)}{\sum_{k=1}^n \text{Updated Weights}_k} \quad \text{Equation 2}$$

The WSM model recalculates overall scores automatically, where, if a site's ranking is stable across all scenarios, it is considered a robust replication candidate. If rankings fluctuate, the candidate is classified as sensitive to weight uncertainty, and additional investigation (e.g. additional sampling) is recommended.

2.5 Final selection process

The three sustainability pillars were assigned weights reflecting their relative importance to the project's holistic success. While Technical Feasibility remains the primary driver ($w = 0.35$), the sustainability core accounts for 65% of the total decision-

making weight. These pillar weights reflect the project's core objectives and the regulatory landscape governing EU-funded technology replication initiatives. Pillar weights and justification behind this is presented in Table 5.

Table 5. Pillar weights for the MCDA assessment

Pillar	Pillar Weight	Justification for weight assignment
Technical Feasibility	0.35	Highest Priority: As the replication study focusing on advancing a technology, this weight ensures the highest score is given to sites whose operational parameters closely match the one of the treatment trains.
Environmental Performance	0.25	This weight value reflects the high-importance requirement for the replication to demonstrate a net positive or minimal environmental impact. It prioritizes sites with advanced practices in water management, emission reduction, and established circularity protocols.
Economic Impact	0.20	This weighting ensures that the selected replication site has the financial scale, resource longevity, and ensure sustained operation of the treatment train beyond the project lifecycle.
Social Acceptance (Socio-Political)	0.20	A successful replication must be socially accepted by the host communities. This weight ensures that sites with robust commitments to workforce development, continuous stakeholder dialogue, and local value creation receive high scores.

The methodological framework integrates technical feasibility, sustainability performance, and structured decision-making into a transparent, reproducible evaluation system. By combining qualitative sustainability assessments with quantitative technical parameters through the MCDA-WSM method, the project ensures that the selected replication site is both technically compatible with the treatment train and aligned with EU sustainability goals.

It should be noted that, the scoring methodology for the developed MCDA followed a hybrid approach. For the technical feasibility assessment, scores were assigned based on expert opinion regarding operational requirements and chemical thresholds. In contrast, the sustainability pillar utilized a 'Criteria-Based Scoring' logic. Here (as it will be discussed in the Results section), scores were determined by presence of international standards (e.g., ISO 14001, TCFD reporting) and companies' general policy ensuring that the sustainability assessment remained grounded in verifiable, evidence-based performance rather than subjective interpretation.

3. Results

This section presents the comprehensive results of the Multi-Criteria Decision Analysis, integrating the findings from both the sustainability assessment and the technical feasibility analysis to analyse the four mines operational adaptability to Resilex treatment train forming the basis of the replication exercise.

3.1 Sustainability pillar assessment

Quantitative results of the Multi-Criteria Decision Analysis (MCDA) for the four candidate mine sites (A, B, C, and D) across the three sustainability pillars (Environmental, Economic, and Social) are presented in Appendix 6.2.

As mentioned in Section 2.2. the scores are normalized to a 0–1 scale to allow for direct comparison with the technical feasibility assessment, and to be consistent with the Weighted Sum Model (WSM) methodology.

To ensure a solid translation of the collected qualitative data to the quantification scores, statements such as a "high percentage of local jobs created (Mine A)" or a specific "Net Zero deadline (Mine D)", were directly assigned the highest scores 1 as they represent definitive, auditable metrics. Furthermore, explicit, high-level commitments with a systematic reference (e.g., ISO 14001 certification in Mine A) received a 1.00 (Excellent). Other strong stated policies or general best practices received scores of 0.75 (Good). The 0.5 (neutral) score assigned when a mine explicitly mentions a goal (e.g., "reducing emissions") but does not provide a specific, time-bound target (such as a "Net Zero 2050" deadline) or a quantified metric to measure. In case, for a critical factor no specific information or policy detail was provided in the collected data, it was conservatively assigned a score of 0 (although it does not necessary means this is the case for the company).

Results of the sustainability assessment shows that; Mine A significantly outperforms all other candidates in the Environmental (score: 0.786) and Economic (score: 0.917) pillars. Its high environmental score reflects superior performance in addressing climate change, decarbonization and efficient water management, while its economic score highlights its dominant role in regional development and local jobs created. However, Mine A shows a moderate performance in social acceptance due to lack of provided information regarding rights of people, matching Mine B but falling behind the others.

In contrast, Mine D emerges as the leader in the Social Pillar (score: 0.700), indicating stronger performance in areas such as human rights, rights of indigenous people, and commitment to social development compared to its peers. Mine C maintains a balanced

profile, particularly in economic and social metrics, while Mine B records the lowest economic impact score among the group mainly due to lower performance in sub-contracting the local companies.

3.2 Technical feasibility assessment

Table 6 shows the score legend used in the feasibility assessment which provides a standardized metric for evaluating how well a mine site's liquid stream and solid waste aligns with the specific design of the Resilex replication technology.

Table 6. Score legend feasibility assessment

Score legend					
Parameter/score	0	0.25	0.5	0.75	1
ppm Cu	<10	10-50	50-100	100-200	>200
ppm Co	<1	1-5	5-10	10-50	>50
ppm Ni	<0.5	0.5-1	1-5	5-10	>10
ppm Zn	<50	50-150	150-250	250-500	>500
ppm (REE, As, Sb, V, Sr, Sc)	<0.5	0.5-1	1-5	5-10	>10
m ³ /year	<10000	10000-50000	50000-200000	200000-500000	>500000
pH	<2,0 o >6,5	5-6,5	2,0-3,5	3,5-4,5	4,5-5
s wt (%)	<300	300-340	340-380	380-420	>420
Waste (kg/t)	>1200	1000-1200	850-1000	700-850	<700

The Technical feasibility result tables for each of mines (A-D) is presented in Appendix 6.3. Mine A is the best candidate as its Cu concentration (339 mg/l) together with the flow rate (876000 m³/year) falls within the 1 (excellent) score scale. It also shows a very good match (score 0.75) for Zn concentration (491 mg/l) and other valuable metal concentrations (7.2 mg/l). The overall score of mine A in the MCDA template is 0.767. Mine B and Mine C show the same pattern; Mine B got the best score match (1) for Zn concentration (710mg/l), other valuable metal concentration (25mg/l) and water flow rate (876000 m³/year). Mine C has the best match (score 1) for Cu (485mg/l), Co (134 mg/l), Zn (1328 mg/l) and other valuable metal concentrations (520mg/l) but got the worst match with score 0 for water flow rate (4380 m³/year) and pH range (0.5) while scores of 0.5 and 0.25 for sulphur concentration and waste volume. The overall scores for mine B and C in the MCDA template are 0.733 and 0.575 respectively. Mine D shows the score value of 0.688 in the MCDA template. For mine D, the highest score value is 0.75 for Zn metal concentration (453mg/l) whereas this value is 0.25 for all other major metal concentrations (Cu= 15 mg/l, Co= 2.46 mg/l and Ni= 0.95 mg/l). The waste stream values for mine D are 0.75 and 0.25 for sulphur concentration and waste volume respectively.

Following the aggregation of all performance indicators, the candidate mines were ranked based on their combined technical and sustainability performance (Appendix 6.4). Mine A achieved the highest overall score of 0.75, driven by its superior technical feasibility and high level of environmental compliance (including ISO 14001 certification). Mine D secured the second position with a score of 0.69, reflecting strong corporate sustainability commitments despite slightly lower technical concentrations compared to the primary site. Mine B (0.64) and Mine C (0.60) followed respectively; while both showed promise in specific treatment train parameters, they were primarily limited by data gaps in their sustainability reporting and lower trace metal recovery potential. These results indicate that Mine A offers the most balanced profile for the successful replication of the treatment train under EU responsible sourcing frameworks. Figure 2 illustrates the comparative rankings of Mines A–D across all assessment pillars, alongside their final aggregated scores

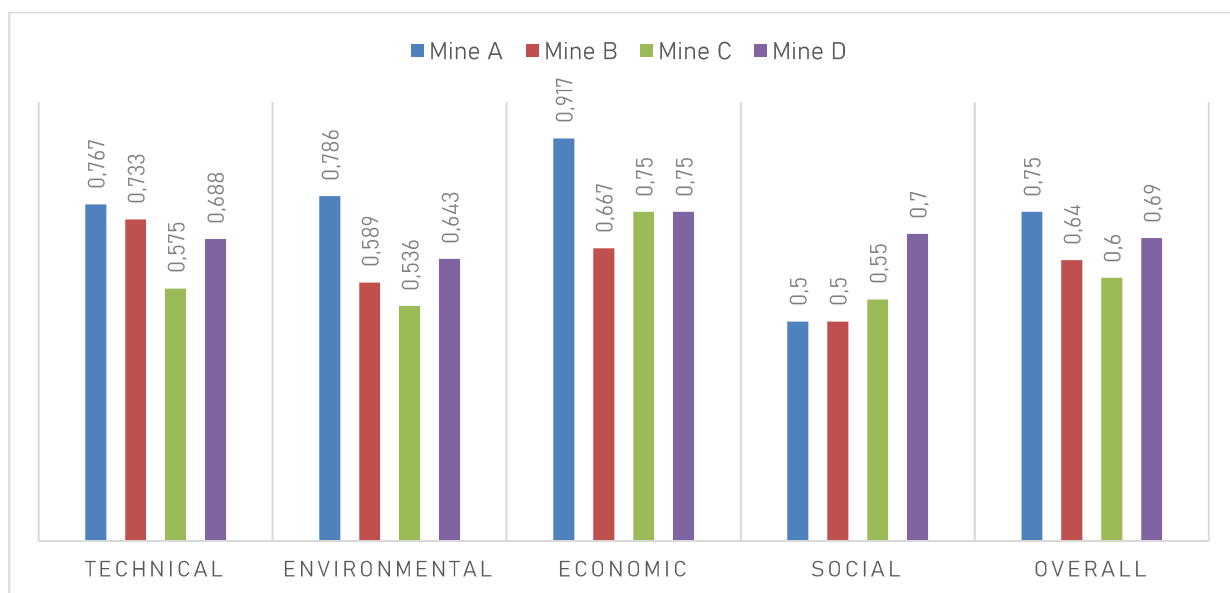


Figure 2. Technical, sustainability and overall rankings of the studied Mines A–D

3.3 Sensitivity analysis and model robustness

The sensitivity analysis was performed to evaluate the stability of the ranking by adjusting the original pillar weights across the four mines (Technical: 0.35; Environmental: 0.25; Economic: 0.20; Social: 0.20) by +/-10%. The resulting scores were normalized to a total weight of 1.0 to ensure a consistent comparative baseline. As presented on Table 7, it was observed that while absolute scores slightly fluctuated (e.g., Mine A ranging from 0.744 to 0.745), the relative ranking of the mines remained unchanged. This result confirms that Mine A consistently outperforms the other

candidates regardless of minor shifts in the prioritization of technical versus sustainability criteria.

Table 7. Sensitivity analysis result

Mine	Original score	Score (-10% weight)	Score (+10% weight)	Final rank stability
A	0.75	0.744	0.745	1 st (stable)
D	0.69	0.689	0.691	2 nd (stable)
B	0.64	0.633	0.636	3 rd (stable)
C	0.6	0.6	0.591	4 th (stable)

The negligible nature the sensitivity analysis outcome indicates that the model is robust and that the selection of Mine A as the primary replication site remains valid. This consistency confirms that the final assessment is not excessively dependent on a single pillar but rather reflects a balanced performance across both technical and sustainability criteria.

4. Conclusions

The Multi-Criteria Decision Analysis (MCDA) identifies Mine A as the optimal candidate for Resilex treatment train replication. This selection is driven by its very good technical adaptability and a notably more robust sustainability profile compared to the other mine sites. Technically, Mine A demonstrates a very close alignment with the project's requirements, specifically matching the necessary industrial scale through its hydraulic flow rate and copper, zinc and valuable metals concentrations. In case of other mines, Mine C presents the high compatibility for concentrations of Copper, Cobalt, and Zinc, yet its viability is compromised by a critically low water volume and an unfavourable pH range that would necessitate high chemical intervention. Mine B demonstrates strong potential for Zinc recovery and matches Mine A's hydraulic scale but necessary adaptive scores across all primary metals. Similarly, Mine D shows some limitation in liquid stream values and favourable matches for Zinc and sulphur concentration.

From a sustainability perspective, Mine A stands out due to its referencing on verifiable international standards and measurable metrics. Its environmental and economic performance is anchored in established frameworks such as ISO 14001 for management and TCFD for climate-related risk disclosure, which provide a more solid and auditable data foundation than the more qualitative reporting seen in other sites. Although Mines B, C, and D each demonstrated localized strengths (e.g. Mine D's high social performance), they achieved lower final MCDA assessment values due to data gaps or technical limitations, effectively clustering them as secondary options behind the comprehensive performance of Mine A.

The sensitivity analysis confirms a high degree of rank stability across all four tested scenarios. While the absolute performance scores slightly fluctuated, the hierarchical order of the mines remained constant ($A > D > B > C$). Notably, the minimum sensitivity score of the primary candidate, Mine A (0.744), remained higher than the base scores of the other candidates, further validating the selection of Mine A as the most resilient site for technology replication.

While all four mines demonstrate a baseline level of sustainability performance consistent with European mining standards, there is a clear opportunity for improvement to meet evolving regulatory expectations. Future sustainability reports should move beyond general policy statements and align with the European Sustainability Reporting Standards (ESRS) or the Global Reporting Initiative (GRI) to ensure more transparent and comparable disclosures. To enhance their sustainability profiles, these sites could specifically target improvements in factors where scores

were currently low or absent, such as biodiversity protection, the integration of recycled materials and respecting rights of indigenous people.

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6. Appendix

6.1 Designed questionnaire; sustainability data collection

Resilex is a Horizon Europe project with the main objective of improving the resilience and sustainability of critical raw material value chain in Europe. To reach this goal, the project runs technological and business innovative solutions covering the full Silicon value chain.

Resilex Work Package 2 aims to develop innovative treatment solutions to recover critical and valuable raw materials, to valorise the potential markets for the recovered materials and to create a replication plan for other mining operations. To achieve this goal, the characterisation of critical raw materials sources in the mineral extraction sector and industrial by-products wastewater from the mineral extraction were analysed by Cetaqua (the WP leader) to evaluate the potential recovery of CRM. The results from analysed samples showed high concentrations of target metals (Zn, Cu, Co, Ni and Cd). Cetaqua then has created a resource recovery treatment train made up of seven units: physico-chemical, sulphide precipitation and membrane anaerobic bioreactor, ion exchange, furnace and combustion gases treatment, sulphuric acid production, acid recovery, and evaporator-crystalliser. The constructed Resilex resource recovery (RR) treatment train treats 25 L/h of acidic wastewater in the physico-chemical stage where the mass balances show that Cu and Zn could increase their concentration up to 7 times in the form of sulphides. Similarly, Co and Ni could be potentially concentrated more than 50000 times, precipitating Co in the form of sulphates and reaching 94 g/L for Ni. In addition, the RR also produces sulphuric acid of 50% concentration from mining waste.

The replicability of Resilex treatment train technology

The objective of the Resilex replication task is to evaluate the replication of the RR Treatment Train for the recovery of CRM in other mining operations, geographical context and sectors where the treatment train can be applied. Recovering critical and valuable metals from acid mine drainage (AMD) is an important process for environmental remediation and resource recovery. Critical raw materials (CRM) recovered from the mining industry waste with high levels of purity, where the utilisation of each precipitate is maximised, enable their reuse and offsetting the costs associated with water treatment.

Our recovered and valorised materials reduce primary extraction (and associated costs and environmental impacts), reduce dependency on imports, avoid landfilling, and reduce the cost of raw materials. The Resilex treatment train not only recovers CRM from acid wastewater and produces sulphuric acid from mining wastes, but also

ensures a circular process by continuously reusing, recycling, and recovering materials within the system. This approach minimises waste and reduces the consumption of raw materials. All the hydrosulphide consumed by the system is produced on-site by the An-MBR, which also mitigates the environmental impact of other industries (e.g., dairy, olive oil, and distillery) by using their organic waste as a substrate. In addition, the sulphate converted by the bacteria is sourced from within the system by recirculating the IEX effluent to the An-MBR. Furthermore, the sulphuric acid used in the IEX unit is produced on-site by reusing mining waste. Our technical partners in the project are in particular interested in valorisation of mine wastes to benefit valuable metals like Cu, Zn or Au, critical metals (CRM) like cobalt or antimony and REE contained on it. Moreover, this process can produce sulfuric acid that will replace fresh sulfuric acid needed by Cetaqua in the adsorption unit, so a mine waste with a sulphur content above 32% is needed to treat in the treatment train.

The information collected in this interview will be used exclusively for research purposes. We take the required actions to assure all the participants information and collected data provided for Resilex will be kept secure based on EU Data Protection and Privacy legal framework and in specific with the General Data Protection Regulation (GDPR) and will only be accessible to the project consortium. Results from this research will be published for academic purposes and the project deliverables only and will be referred to anonymously, i.e., it will not be possible to trace back your organization or exclusive contribution.

Please send this questionnaire with your answers to Shervin Shahvi at s.shahvi@imperial.ac.uk

1. Site characteristics

1.1 Where the mine is located

1.2 What is the usual climate type in the area

1.3 Is the mine close to any water body

1.4 What is the main land use in surroundings (e.g. agriculture, urban)

2. Water quantity and quality

2.1 What is the main water source in the area (surface water, groundwater, others)

2.2 In general, what is the water quantity situation in area in terms of volume and fluctuations

2.3 In general, what are the treatment level the water sources undergo before using by residents and the industry sectors?

2.4 Are there any secondary resources that can be tapped and benefitted from after treatment?

3. Ore and waste composition

3.1 What is the site main ore and waste type in terms of mineralogy and metals concentration?

3.2 What are the main tailing composition of the site, chemical and physical properties and potential acid generation

3.3 Where do the tailings come from?

4. Wastewater composition

4.1 What is the general concentration content of the waste streams, in terms of metals, sulphates and their pH?

4.2 If the mine has an ore treatment plant, what waste is generated, and can it be reused for other purposes?

5. Treatment situation

5.1 What are treatment targets and regulatory standards for released water in the area

5.2 What are the current treatment technologies applied for the wastewater streams of the mine?

5.3 What is the current daily water volume being treated in the mine facility?

6. Waste management

6.1 What is the waste management policy for the mine in terms of handling and storage of slides?

6.2 Are there any water or metal recovery activities in the mine?

6.3 Are there any potential for adaptation of new recovery infrastructure

6.4 Are there any strategies for post application of mine wastes (e.g., recovery, valorisation and selling)

7. Environmental considerations

7.1 What is the main ecosystem in the area (wetland, habitant, species)

7.2 Is there any land-use restrictions and sensitivity area in the surrounding area?

7.3 Have the area experienced any extreme weather events such as heavy rain or drought in recent years?

8. Economy and financial factors

8.1 What are the main income sources for the people in the area?

8.2 Have the area experienced any recession or fluctuations in local market or jobs in recent years?

7.3 What could be a potential budget for the main to set-up a treatment facility?

6.2 MCDA; sustainability assessment results

Table 8. Environmental factors of sustainability assessment

Environmental factors	Mine A	Mine B	Mine C	Mine D
Addressing climate change / Decarbonization	1	0.5	0.5	1
Reducing GHG emissions	1	0.5	0	1
Carbon footprint	1	0	0.75	0.75
Net zero greenhouse gas (GHG) emissions	0.5	0	0.5	1
Managing climate-related risks	1	0.5	0	0.5
Environmental policy / Environmental management	1	0.75	0.75	0.75
Efficient water management	1	1	0.75	1
Protection of water sources	1	1	0.5	0.75
Minimize environmental impacts	0.75	0.75	0.75	0.75
Biodiversity and sensitive species	0.5	0.75	0	0.5
Recycling metals	0	0.	1	0
Reducing the amount of waste deposited	0.5	1.	0.5	0
Safe tailing management	1	0.5	0.75	0.5
Responsible waste management / Ensure long-term, sustainable disposal	0.75	1	0.75	0.5

Table 9. Economic factors of sustainability assessment

Economic factors	Mine A	Mine B	Mine C	Mine D
Regional economic development	1	1	0.75	0.75
Local jobs created	1	1	0.75	0.75
Subcontracting local companies	0.75	0	0.75	0.75

Table 10. Social factors of sustainability assessment

Social factors	Mine A	Mine B	Mine C	Mine D
Conserve historical heritage	1	0	0	0.75
Human rights	0	0.75	0	0.75
Rights of indigenous peoples	0	0	1	0.5

Employees safety and occupational health management policies	0.5	0.75	1	0.75
Committed to the social development and well-being of communities	1	1	0.75	0.75

6.3 MCDA; technical feasibility assessment results

Table 11. Mine A technical feasibility values

Category	Parameter	Weight	Score (0-1)	Weighted Score
Liquid stream	Cu metal concentration (339 mg/l)	0.1333	1	0.1
Liquid stream	Co metal concentration (7.5 mg/l)	0.1333	0.5	0.05
Liquid stream	Ni metal concentration (1.3 mg/l)	0.1333	0.5	0.05
Liquid stream	Zn metal concentration (491 mg/l)	0.1333	0.75	0.075
Liquid stream	Other valuable metals concentration (7.2 mg/l)	0.1333	0.75	0.075
Liquid stream	Water flow rate (876000 m ³ /y)	0.2667	1	0.2
Liquid stream	pH range (2.5)	0.0668	0.5	0.025

Table 12. Mine B technical feasibility values

Category	Parameter	Weight	Score (0-1)	Weighted Score
Liquid stream	Cu metal concentration (53 mg/l)	0.1333	0.5	0.05
Liquid stream	Co metal concentration (4.36 mg/l)	0.1333	0.25	0.025
Liquid stream	Ni metal concentration (3.5 mg/l)	0.1333	0.5	0.05
Liquid stream	Zn metal concentration (710 mg/l)	0.1333	1	0.1
Liquid stream	Other valuable metals concentration (25 mg/l)	0.1333	1	0.1
Liquid stream	Water flow rate (876000 m ³ /y)	0.2667	1	0.2
Liquid stream	pH range (2.8)	0.0668	0.5	0.025

Table 13. Mine C technical feasibility values

Category	Parameter	Weight	Score (0-1)	Weighted Score
Liquid stream	Cu metal concentration (485 mg/l)	0.1	1	0.1
Liquid stream	Co metal concentration (134 mg/l)	0.1	1	0.1
Liquid stream	Ni metal concentration (8.12 mg/l)	0.1	0.75	0.075
Liquid stream	Zn metal concentration (1328 mg/l)	0.1	1	0.1
Liquid stream	Other valuable metals concentration (520 mg/l)	0.1	1	0.1
Liquid stream	Water flow rate (4380 m ³ /y)	0.2	0	0
Liquid stream	pH range (0.5)	0.05	0	0
Solid waste	Sulphur concentration (wt%) (375 kgS)	0.15	0.5	0.1125
Solid waste	Waste volume (quantity) (1000 kg/t)	0.1	0.25	0.1

Table 14. Mine D technical feasibility values

Category	Parameter	Weight	Score (0-1)	Weighted Score
Liquid stream	Cu metal concentration (15 mg/l)	0.1	0.25	0.025
Liquid stream	Co metal concentration (2.46 mg/l)	0.1	0.25	0.025
Liquid stream	Ni metal concentration (0.95 mg/l)	0.1	0.25	0.025
Liquid stream	Zn metal concentration (453 mg/l)	0.1	0.75	0.075
Liquid stream	Other valuable metals concentration (6 mg/l)	0.1	0.5	0.05
Liquid stream	Water flow rate (75000 m ³ /y)	0.2	0.5	0.1
Liquid stream	pH range (2.5)	0.05	0.5	0.025
Solid waste	Sulphur concentration (wt%) (420 kg S)	0.15	0.75	0.15
Solid waste	Waste volume (quantity) (1000 kg/t)	0.1	0.25	0.1

6.4 MCDA final assessment

Table 15. MCDA assessment, Mine A

Pillar	Pillar Weight (0-1)	Sub-criterion	Sub-weight	Score (0-1)	Weighted Sub-score	Pillar Total	Pillar Weighted
Technical	0.35	Cu metal concentration	0.1333	1	0.133	0.767	0.268
		Co metal concentration	0.1333	0.5	0.067		
		Ni metal concentration	0.1333	0.5	0.067		
		Zn metal concentration	0.1333	0.75	0.100		
		Other valuable metals concentration	0.1333	0.75	0.100		
		Water volume	0.2667	1	0.267		
		pH range	0.0668	0.5	0.033		
Environmental	0.25	Addressing climate change / Decarbonization	0.071	1	0.071	0.786	0.196
		Reducing GHG emissions	0.071	1	0.071		
		Carbon footprint	0.071	1	0.071		
		Net zero greenhouse gas (GHG) emissions	0.071	0.5	0.036		
		Managing climate-related risks	0.071	1	0.071		
		Environmental policy / Environmental management	0.071	1	0.071		
		Efficient water management	0.071	1	0.071		
		protection of water sources	0.071	1	0.071		
		Minimize environmental impacts	0.071	0.75	0.054		
		Biodiversity and sensitive species	0.071	0.5	0.036		
		Recycling metals	0.071	0	0.000		
		Reducing the amount of waste deposited	0.071	0.5	0.036		
		Safe tailing management	0.071	1	0.071		
		Responsible waste management / Ensure long-term, sustainable disposal	0.071	0.75	0.054		
Economic	0.2	Regional economic development	0.333	1	0.333	0.917	0.183
		Local jobs created	0.333	1	0.333		

		Subcontracting local companies	0.333	0.75	0.250		
Social	0.2	Conserve historical heritage	0.2	1	0.200	0.500	0.100
		Human rights	0.2	0	0.000		
		Rights of indigenous peoples	0.2	0	0.000		
		Employees safety and occupational health management policies	0.2	0.5	0.100		
		Committed to the social development and well-being of communities	0.2	1	0.200		
						Overall Score	0.75

Table 16. MCDA assessment, Mine B

Pillar	Pillar Weight (0-1)	Sub-criterion	Sub-weight	Score (0-1)	Weighted Sub-score	Pillar Total	Pillar Weighted
Technical	0.35	Cu metal concentration	0.1333	0.5	0.067	0.733	0.257
		Co metal concentration	0.1333	0.25	0.033		
		Ni metal concentration	0.1333	0.5	0.067		
		Zn metal concentration	0.1333	1	0.133		
		Other valuable metals concentration	0.1333	1	0.133		
		Water volume	0.2667	1	0.267		
		pH range	0.0668	0.5	0.033		
Environmental	0.25	Addressing climate change / Decarbonization	0.071	0.5	0.036	0.589	0.147
		Reducing GHG emissions	0.071	0.5	0.036		
		Carbon footprint	0.071	0	0.000		
		Net zero greenhouse gas (GHG) emissions	0.071	0	0.000		

		Managing climate-related risks	0.071	0.5	0.036		
		Environmental policy / Environmental management	0.071	0.75	0.054		
		Efficient water management	0.071	1	0.071		
		protection of water sources	0.071	1	0.071		
		Minimize environmental impacts	0.071	0.75	0.054		
		Biodiversity and sensitive species	0.071	0.75	0.054		
		Recycling metals	0.071	0	0.000		
		Reducing the amount of waste deposited	0.071	1	0.071		
		Safe tailing management	0.071	0.5	0.036		
		Responsible waste management / Ensure long-term, sustainable disposal	0.071	1	0.071		
Economic	0.2	Regional economic development	0.333	1	0.333	0.667	0.133
		Local jobs created	0.333	1	0.333		
		Subcontracting local companies	0.333	0	0.000		
Social	0.2	Conserve historical heritage	0.200	0	0.000	0.500	0.100
		Human rights	0.2	0.75	0.150		
		Rights of indigenous peoples	0.2	0	0.000		
		Employees safety and occupational health management policies	0.2	0.75	0.150		
		Committed to the social development and well-being of communities	0.2	1	0.200		
						Overall score	0.64

Table 17. MCDA assessment, Mine C

Pillar	Pillar Weight (0-1)	Sub-criterion	Sub-weight	Score (0-1)	Weighted Sub-score	Pillar Total	Pillar Weighted
Technical	0.35	Cu metal concentration	0.100	1.000	0.100	0.575	0.201
		Co metal concentration	0.100	1.000	0.100		
		Ni metal concentration	0.100	0.750	0.075		
		Zn metal concentration	0.100	1.000	0.100		
		Other valuable metals concentration	0.100	1.000	0.100		
		Water volume	0.200	0.000	0.000		
		pH range	0.050	0.000	0.000		
		Sulphur concentration (wt%)	0.150	0.500	0.075		
		Waste volume (quantity)	0.100	0.250	0.025		
Environmental	0.25	Addressing climate change / Decarbonization	0.071	0.500	0.036	0.536	0.134
		Reducing GHG emissions	0.071	0.000	0.000		
		Carbon footprint	0.071	0.750	0.054		
		Net zero greenhouse gas (GHG) emissions	0.071	0.500	0.036		
		Managing climate-related risks	0.071	0.000	0.000		
		Environmental policy / Environmental management	0.071	0.750	0.054		
		Efficient water management	0.071	0.750	0.054		
		protection of water sources	0.071	0.500	0.036		
		Minimize environmental impacts	0.071	0.750	0.054		
		Biodiversity and sensitive species	0.071	0.000	0.000		
		Recycling metals	0.071	1.000	0.071		
		Reducing the amount of waste deposited	0.071	0.500	0.036		

		Safe tailing management	0.071	0.750	0.054		
		Responsible waste management / Ensure long-term, sustainable disposal	0.071	0.750	0.054		
Economic	0.2	Regional economic development	0.333	0.750	0.250	0.750	0.150
		Local jobs created	0.333	0.750	0.250		
		Subcontracting local companies	0.333	0.750	0.250		
Social	0.2	Conserve historical heritage	0.200	0.000	0.000	0.550	0.110
		Human rights	0.200	0.000	0.000		
		Rights of indigenous peoples	0.200	1.000	0.200		
		Employees safety and occupational health management policies	0.200	1.000	0.200		
		Committed to the social development and well-being of communities	0.200	0.750	0.150		
						Overall score	0.6

Table 18. MCDA assessment, Mine D

Pillar	Pillar Weight (0-1)	Sub-criterion	Sub-weight	Score (0-1)	Weighted Sub-score	Pillar Total	Pillar Weighted
Technical	0.35	Cu metal concentration	0.100	0.250	0.025	0.688	0.241
		Co metal concentration	0.100	0.250	0.025		
		Ni metal concentration	0.100	0.250	0.025		
		Zn metal concentration	0.100	0.750	0.075		
		Other valuable metals concentration	0.100	0.500	0.050		
		Water volume	0.200	0.500	0.100		
		pH range	0.050	0.500	0.025		

		Sulphur concentration (wt%)	0.150	0.750	0.113		
		Waste volume (quantity)	1.000	0.250	0.250		
Environmental	0.25	Addressing climate change / Decarbonization	0.071	1.000	0.071	0.643	0.161
		Reducing GHG emissions	0.071	1.000	0.071		
		Carbon footprint	0.071	0.750	0.054		
		Net zero greenhouse gas (GHG) emissions	0.071	1.000	0.071		
		Managing climate-related risks	0.071	0.500	0.036		
		Environmental policy / Environmental management	0.071	0.750	0.054		
		Efficient water management	0.071	1.000	0.071		
		protection of water sources	0.071	0.750	0.054		
		Minimize environmental impacts	0.071	0.750	0.054		
		Biodiversity and sensitive species	0.071	0.500	0.036		
		Recycling metals	0.071	0.000	0.000		
		Reducing the amount of waste deposited	0.071	0.000	0.000		
		Safe tailing management	0.071	0.500	0.036		
		Responsible waste management / Ensure long-term, sustainable disposal	0.071	0.500	0.036		
Economic	0.2	Regional economic development	0.333	0.750	0.250	0.750	0.150
		Local jobs created	0.333	0.750	0.250		
		Subcontracting local companies	0.333	0.750	0.250		
Social	0.2	Conserve historical heritage	0.200	0.750	0.150	0.700	0.140

		Human rights	0.200	0.750	0.150		
		Rights of indigenous peoples	0.200	0.500	0.100		
		Employees safety and occupational health management policies	0.200	0.750	0.150		
		Committed to the social development and well-being of communities	0.200	0.750	0.150		
						Overall score	0.69

