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Multi-Criteria Decision Analysis for Evaluating Transitional and Post-Mining Options—An Innovative Perspective from the EIT ReviRIS Project

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Abstract: In mine design and planning, identifying appropriate Post-Mining Land Use (PMLU) is necessary and crucial to achieving environmental quality and socioeconomic renewal. In this context, Multi-Criteria Decision Making (MCDM) methods are used to support decision-maker and stakeholder decisions. However, most studies regarding the application of MCDM methods to PMLU decisions do not favor their widespread use because they start from an already structured decisional problem. The structure they present may not apply to another PMLU decision. Therefore, the primary goal of this study is to present an innovative methodology and its corresponding framework to help decision-makers and stakeholders structure their PMLU decisions. This innovative methodology can be used from an early stage, with a low level of detail, until a later stage, with a high level of detail, and is composed of three main stages. The first stage is selecting the Transitional Post-Mining Landscape Profile, which guides the user to different Multi-Criteria Decision Analysis (MCDA) goals. The second stage is developing criteria and alternatives according to the MCDA goal, using topics representing essential dimensions that cannot be disregarded, and testing the MCDM methods. Finally, the third stage is the participatory process and final application of MCDM methods.

Keywords: ReviRIS; post-mining land use; MCDA; revitalization; participatory tool; mine closure

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1. Introduction

PMLU is a key issue regarding the public image of the mining industry. Mines abandoned over the last century have been posing environmental risks to water, soil, and air, with impacts on local populations and demands for government management. However, with more restrictive environmental-impact legislation, no mining activity presently exists without a proper closure and rehabilitation plan in European Union (EU) countries. The experience gained in more recent decades demonstrates that it is not enough to control and reclaim environmental damages, or to reclaim the landscape features without considering the attribution of new functions to the site, called a revitalization process.

In EU countries, the revitalization of mine sites has become crucial to achieving social acceptance for mining projects. First, however, future land use needs to be studied, analyzed, and selected from a set of scenarios before and during the revitalization process. MCDA is applied to this context to develop an approach that involves and integrates different, and often conflicting criteria to which distinct solutions exist for the selection. This approach follows a series of stages [1], namely (1) identification of the problem, (2) problem structuring, (3) model building, (4) using the model to inform and challenge thinking, and (5) developing an action plan. Each stage involves different procedures and techniques to structure the problem as close to reality.

When an MCDA is developed to the point where a decision is missing, it becomes a well-structured MCDM problem [1] with defined criteria and alternatives. However, this is not a common situation [1]. Alternatives include solutions, projects, or scenarios under evaluation that are developed to achieve the MCDA goal(s); the criteria include elements, defined as small sentences and as smaller objectives, that describe and evaluate these alternatives ([2], Ch. 2.1). Often, criteria are arranged in a hierarchy and sub-divided into attributes, generally used in the Analytic Hierarchy Process (AHP). There are distinct methods for applying an MCDM problem to help decision-makers choose an alternative, among others, each with its advantages and disadvantages.

Some PMLU studies have been conducted as MCDM problems because they start from an already structured problem and apply one method or a combination of two [3–7]. For example, in the study developed by Soltanmohammadi et al. [3–5], a framework for the suitability of the mined land for new use, is created based on the concept developed by Knabe [8], called a Mined Land Suitability Analysis (MLSA). This framework comprises 50 attributes divided into four main criteria used to assess 23 specific alternatives divided into eight land use categories. In addition, these studies use a combination of methods: AHP is used for criteria weighting, and other methods are used for alternatives assessment (TOPSIS, ELECTRE, and PROMETHEE).

Bangian et al. [7] applied the fuzzy AHP method to an MCDM problem (an already structured problem), where a link between the Optimal Post-Mining Land Use (OPMLU) of the open pit and the Net Present Value (NPV) of the mine were made known. This link was suggested because, considering the need for closure planning at the feasibility and pre-feasibility stage of a mining project, the PMLU of the most affected area (usually, the open pit) influences the NPV. In this MCDM, the problem structure comprises 17 alternatives and 96 attributes, distributed among five main criteria.

These kinds of studies [3–7] use a large number of fixed criteria and alternatives. Their widespread application to PMLU MCDA is uncertain because they require the evaluation of dozens of elements that may not describe or characterize different mine sites. In addition, the AHP method allows for higher subjectivity instead of objectivity, and these studies do not include the spatial characteristics of mining activities and land use planning. Therefore, PMLU MCDA requires the development of a framework that, through a guided-thought process, helps field experts develop better alternatives and define specific criteria. At the same time, the inclusion of Geographic Information System (GIS) data is crucial to consider all elements and to be able to adapt to specific sites in a general process.

This study aims to develop an innovative framework, used as a methodology for post-mining planning, that will guide and help decision-makers and stakeholders make decisions and find the best compromising solution. To achieve this aim, in Section 2—Materials and Methods—(i) the Transitional Post-Mining Landscape Profile (TPMLP) is defined to allow the decision-maker to realize the steps required for implementation of the revitalization process, (ii) topics are defined and applied to all post-mining decision-making problems, and (iii) MCDM methods are carefully selected to analyze alternatives and define the new land uses. Then, in Section 3—Results and Discussion—all of these aspects are discussed and integrated into the ReviRIS decision process for PMLU.

2. Materials and Methods

This section defines and describes the elements that are integrated into the ReviRis methodology. First, we define and describe the TPMLP, the starting point of this methodology. Second, we define and describe the topics, upon which the alternatives and criteria should be based according to the characteristics of the mining site and the decisional problem. Finally, we describe the MCDM methods suggested for this methodology, which are the following: the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), Sequential Interactive Method for Urban Systems (SIMUS), and Simple Multi-Attribute Rating Technique Extended to Ranking (SMARTER).

The integration of all these elements is explained in Section 3—Results and Discussion.

2.1. Transitional Post-Mining Landscape Profiles (TPMLP)

To understand how different types of mines fit in a set of categories, the following four conceptual questions were considered:

Q1 Is the site an active mine?
Q2 Does the site have a private entity responsible for the environmental liability?
Q3 Has fieldwork been implemented on site for environmental control and remediation?
Q4 Has fieldwork implemented for revitalization and new land use?

The answers to these questions are "Yes," "No," "Ongoing," or "Completed," and the combination of them leads to the definition of 15 TPMLPs. These combinations allow for grouping the TPMLP into three main categories, namely "abandoned mines," "not active mines," and "active mines". The "abandoned" category represents all mining sites where mining companies left without environmentally reclaiming the site. "Not active mines" refers to quarries that are not abandoned but are instead in a stand-by situation (this is not common in metal mines). Finally, all mining sites with current ore production are in the "active" category. These categories cover the legal status of mines.

Table 1 shows the reference to the conceptual questions; the combination of answers; the main category of the site; and, in the last column, the profile number that corresponds to each answer combination.

Table 1. Combination of possible answers to the questions listed in the text (Q1–Q4).

Q1	Q2	Q3	Q4	Main Category	Profile No.
No	No	No	No	Abandoned	1
No	No	Ongoing	No		2
No	No	Completed	No		3
No	No	Completed	Ongoing		4
No	No	Completed	Completed		5
No	Yes	No	No	Not active	6
No	Yes	Ongoing	No		7
No	Yes	Completed	No		8
No	Yes	Completed	Ongoing		9
No	Yes	Completed	Completed		10
Yes	Yes	No	No	Active	11
Yes	Yes	Ongoing	No		12
Yes	Yes	Completed	No		13
Yes	Yes	Completed	Ongoing		14
Yes	Yes	Completed	Completed		15

The answer to Q1 provides information about whether the site has a mine closure process. With this, the decision process is directed to one of the following starting points of the MCDA:

1. An area that is not expected to have further mineral exploitation, meaning that, from the point of view of terrain modifications, it is in a static situation;

2. An area with active mineral exploitation, meaning that, from the point of view of terrain modifications, it is in a dynamic situation.

Q2 relates to the role that the government or private entities play in the whole process. If the site has no private entity responsible for the environmental remediation, that responsibility is directly attributed to the government. This means that the government must combine efforts to properly design, implement, and monitor technical and environmental remediation. If a private entity is responsible for mining activity, it is responsible for that effort. This question provides insight into the responsibility of stakeholders in ensuring that environmental liabilities are remediated but not into the revitalization project.

Q3 addresses the stage of fieldwork for environmental remediation. This information guides the decision to the level of detail for the definition of a revitalization project, which depends on the results of the terrain modeling and engineering solutions to contain or treat contamination. If fieldwork is not yet implemented, then the main decision falls on the technical and engineering solutions to be applied. However, suppose that the fieldwork is ongoing or completed. In that case, revitalization is directly considered in the decisional process, first by identifying the theme and objectives and second by selecting a proper revitalization plan.

Last, Q4 reflects the attribution of managing responsibilities for the final new land use, and monitoring of the environmental remediation parameters. This decision happens after deciding on the revitalization project, but the fieldwork to implement it is still ongoing. However, the ideal process is where the managing and monitoring responsibilities are accounted for when selecting a revitalization project. Once the revitalization fieldwork are completed, all decisions should have already been taken.

2.2. Topics

Some studies define PMLU or mine reclamation criteria differently depending on the study's approach and the stakeholders involved. There are two main ways of organizing criteria: (i) in a hierarchy with attributes given to sub-levels of each criterion [4,9,10] or (ii) non-hierarchical [11–13] without sub-levels of criteria. The first one divides a complex problem into its main characteristics, the criteria, and enables the decision-maker to assess only one of those characteristics at each time. The second way of organizing criteria enables the decision-maker to analyze the problem through a holistic lens. Aiming for a methodology to be applied, ideally, in all post-mining decision-making problems, this study defines not criteria but topics. These topics are based on the criteria developed by the authors referred to above, but with the novelty of including Geoethics and Regional Development in the process.

Geoethics is a relatively new discipline of geosciences. It is an emerging area that deals with scientific, technological, methodological, and social-cultural aspects, such as sustainability, development, or even museology [14–18]. Geoethics is also concerned with the necessity of considering appropriate protocols, scientific integrity issues, and developing a code of good practice regarding the abiotic world [17], highlighting the importance of geoscientists and their work in the current civilization. Furthermore, one of the focuses of Geoethics is pressing environmental subjects, ensuring adequate and sustainable natural resource usage, promoting appropriate management of natural risks, and diffusing scientific knowledge and geoeducation [14]. All of this have social, cultural, and economic repercussions. For that reason, Geoethics is included in decision processes, enabling the creation of solid guidelines that provide socioeconomic solutions and respect the environment [14].

The reason to consider "topics" and not "criteria" is due to the objective of their creation: they are a checklist when structuring a PMLU MCDA problem to be evaluated in a decision support system. They can be developed further as criteria, constraints, restrictions, or even a theme for designing alternatives, depending on the site's profile and MCDA goal. The topics are Economy, Environment, Technical issues, Social, Geoethics, and

Regional Development. These six topics cover all aspects of every stage of the reclamation and revitalization of mineral exploitation areas and are briefly described in Table 2.

Table 2. Description of ReviRIS topics.

Topic	Description
Economics	Costs related to implementing the alternative or monitoring environmental and safety issues, the time needed to develop such plans, the post-mining land use economic balance, and the funding opportunities or possibilities.
Environmental	This topic is linked with the natural environment, such as atmospheric, aquatic, terrestrial, and biological domains. These domains form the baseline to develop a characterization study of the current state of the mine complex.
Technical issues	It intends to include aspects of the mine site itself and engineering into the decisional process. The main aspects are related to mine's physical characteristics, measures that need to be taken to cope with the type of contamination, characteristics of structures and facilities, potential for the circular economy, terrain characteristics, and stability and risk conditions of the mine complex area.
Social	This topic relates to the economic development of local communities, future employment situation, community cohesion, social structure impact, regional culture and collective identity, fears and aspiration of the local community, safety, health and well-being, land planning, infrastructures, environment, personal and proper rights, and political and institutional stresses.
Regional Development	This topic is new, and its inclusion derives from adding regional strategies, ambitions, and needs into the decisional process. Therefore, the elements accounted for are the potential for agricultural, commercial, touristic, real-state, or other economic activities. The regional strategy for each activity is linked with the regional legislation and legal frameworks regarding land management. The regional strategy for climate change adaptation should also be considered and the site's proximity to local communities.
Geoethics	This new topic intends to enable decision-makers to develop a set of criteria that considers the following: local population needs, natural potential, knowledge gathered through years or decades of mining, safety and health of the whole ecosystem (including humans), and how it interacts with the economic activities, whether through the promotion of culture and tourism or by the preservation of geological and mining heritage.

2.3. Multiple Criteria Decision-Making Methods Applicable to ReviRis Context

In an MCDA, the methods to be used should be carefully selected. There are dozens of MCDM methods ([2], Ch. 4.1.2), each of them has its particularities. After extensive research throughout the main and most commonly used MCDM methods, the ones selected for ReviRIS methodology are TOPSIS developed by Hwang and Yoon [19], SIMUS [20], and the weighting technique used in SMARTER developed by Barron and Barret [21].

There are common mathematical steps to many MCDM methods, as outlined in Figure 1. To further explain, the steps constitute: (1) the preparation of a matrix where, usually, the criteria are provided in rows and the alternatives are provided in columns; (2) the performance values are the values in each intersection between one criterion and one alternative, and they can be qualitative or quantitative; (3) although not mandatory, the criteria's weights can be derived from one of the many weighting methods available and added into the Initial Decision Matrix (IDM); (4) the data added to the IDM may represent different units and scales, which require data normalization; however, the discussion of the most suitable technique goes beyond the study's scope; (5) the application of the mathematical procedure of the method chosen; and finally, (6) ranking of the alternatives according to its scores given by the method applied.

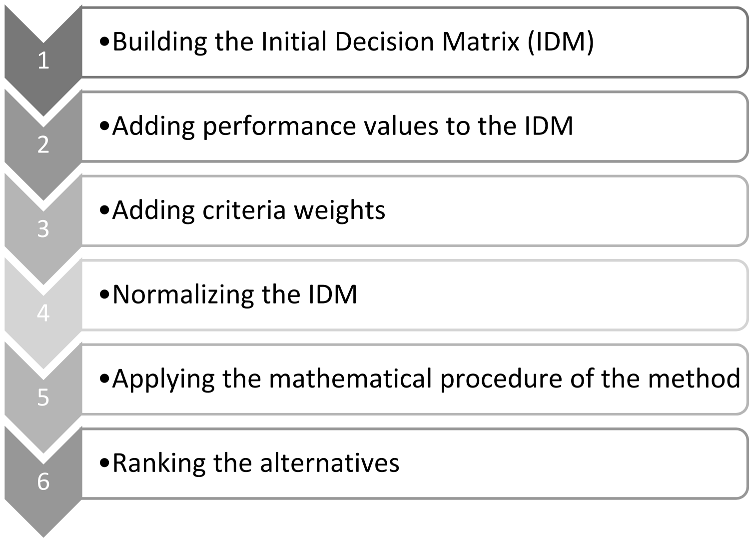

Figure 1. Common steps when applying a Multi-Criteria Decision-Making method.

The mathematical procedure of the three different MCDM methods selected, namely, TOPSIS, SIMUS, and SMARTER, is briefly described in the following sub-sections. The following descriptions correspond to step 5 of Figure 1.

2.3.1. Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)

This method was introduced by Hwang and Yoon [19], which is based on the idea that the "best" alternative is one with the shortest distance from the ideal solution and the farthest from the least-ideal solution. When these distances are considered simultaneously in a mathematical procedure, it measures the relative closeness to the ideal solution, supporting the decision-maker in their choice. For this procedure, actions are added to criteria (maximization or minimization), which is related to the benefit and cost criteria, with the benefit criteria preferring larger values (tend to call for maximization) and the cost criteria preferring smaller values (tend to call for minimization). The specific steps of TOPSIS are the following:

Step 1: Determination of Positive-Ideal and Negative-Ideal Solutions.

The mathematical procedure to define the Positive-Ideal Solution (*PIS*) and the Negative-Ideal Solution (*NIS*), which are artificial extremes for a set of alternatives, follows the following rules:

$$PIS = \{(max_i v_{ij} | j \in J), (min_i v_{ij} | j \in J') \mid i = 1, 2, \ldots, m\} = \left\{v_1^+, v_2^+, \ldots, v_j^+, \ldots, v_n^+\right\} \quad (1)$$

$$NIS = \{(min_i v_{ij} | j \in J), (max_i v_{ij} | j \in J') \mid i = 1, 2, \ldots, m\} = \left\{v_1^-, v_2^-, \ldots, v_j^-, \ldots, v_n^-\right\} \quad (2)$$

where

$J = \{j = 1, 2, \ldots, n | \ j\ associated\ with\ benefit\ criteria\}$,
$J' = \{j = 1, 2, \ldots, n | \ j\ associated\ with\ cost\ criteria\}$,
i is the number of alternatives (1, 2, ... , m),
j is the number of criteria (1, 2, ... , n),
v is the value of jth criterion on the ith alternative,
v_n^+ is the value of the nth criterion of the *PIS* alternative, and
v_n^- is the value of the nth criterion of the *NIS* alternative.

These rules ensure that the artificial positive extreme solution (*PIS*) refers to the most desirable alternative and that the artificial negative extreme solution (*NIS*) refers to the least preferable alternative.

Step 2: Calculation of the separation measure.

After step 1, the TOPSIS method requires calculating the distance between the alternatives to be considered and the *PIS* and *NIS* artificial alternatives. This step is used to "calculate the separation measure" [19] between each alternative and *PIS*, and at a second step, between each alternative and *NIS*, and it uses the Euclidean distances between performance values of the considered alternatives. The equations are as follows:

- "Positive" distances between each alternative to *PIS* alternative

$$D_i^{PIS} = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^{+}\right)^2} \tag{3}$$

- "Negative" distances between each alternative to *NIS* alternative

$$D_i^{NIS} = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^{-}\right)^2} \tag{4}$$

Step 3: Calculation of the relative closeness to the ideal solution.

The final specific step of TOPSIS is the calculation of the relative distance of each alternative to the artificial ones to find the alternative that is closest to *PIS* and farthest to *NIS*, using the following equation:

$$S_{A_i} = \frac{D_i^{NIS}}{D_i^{PIS} + D_i^{NIS}},\ 0 < S_{A_i} < 1 \tag{5}$$

where S_{A_i} represents the relative distance of alternative A_i to *PIS* and *NIS*, which falls between 0 and 1. The closer the value is to 1, the closer the alternative is to *PIS*. This value provides insight to the decision-maker about the alternative to choose.

Although TOPSIS has several mathematical steps, it is a straightforward method to learn and apply.

2.3.2. Sequential Interactive Method for Urban Systems (SIMUS)

SIMUS was developed by Munier in his PhD thesis [20] and further described in Munier [22] and Munier et al. [2]. This method models MCDA problems in which multiple objectives need to be met, dependent criteria are in place, alternatives or projects require precedence over other alternatives, and the number of criteria or alternatives used is not limited. These characteristics enable the application of SIMUS to complex scenarios, such as prioritizing local viable renewable energy sources, urban transport selection, groundwater pumping for irrigation purposes, road projects, and railways planning [23–27].

Able to deal with complex decision problems, SIMUS is a hybrid method that combines Linear Programming (LP) with heuristic methods, namely, weighted sum and outranking procedures ([2], Ch. 7), [25]. It has two main stages. The first stage is the application of the Simplex Linear Programming Algorithm, which enables the method to find optimal solutions, if they exist, for each criterion that is used as an objective function of the LP. This process generates a Pareto Efficient Matrix that holds all of the optimal values for the objective functions (criteria used as such). Then, based on these optimal results, a weighted sum technique is applied to alternatives, that output the first ranking of the alternatives. After the first ranking result, the method applies the outranking technique to examine the dominant alternative on criteria and to calculate the difference between the dominant and subordinated alternatives, giving the second-ranking solution.

The mathematical procedures that provide the robustness of SIMUS to deal with complex scenarios are not too complex to understand. However, to handle complex scenarios, SIMUS uses software, and time is needed to learn to use this software.

2.3.3. Simple Multi-Attribute Rating Technique Extended to Ranking (SMARTER)

The reason we use this method in ReviRIS is that it allows to include stakeholders' preferences regarding the importance of criteria, and therefore, it is suitable for the participatory stage. This method can be applied through a questionnaire designed specifically for the site and problem under appraisal. The answers are aggregated to give weights to criteria and then used in TOPSIS or SIMUS. The studies by Pontiglioni [28] and Assuma et al. [29] use SMARTER for this purpose: to rank criteria according to the preferences of different stakeholders.

Although SMARTER is an MCDM method, the technique that it uses to determine weights, the Rank Order Centroid (ROC) weights [21], is well fitted to weighting the criteria. However, it requires an adaptation of the SMARTER procedure, not to help in the decision regarding which is the best alternative but to help in the reasoning of the collective preference of criteria to address the decision problem under evaluation.

The calculation of ROC weights follows the following equation.

$$w_k = \frac{1}{K} \sum\nolimits_{i=k}^{K} \frac{1}{i} \tag{6}$$

where

k is the ranked position of each criterion;
w_k is the calculated weight (ROC weight); and
K is the total number of criteria, or attributes, to be ranked.

The constraint of this method is that it does not allow for more than 16 criteria because, from that value on, the ROC weight attributed to each criterion is too small. The difference in importance between criteria starts to become irrelevant.

This method is applied at a participatory stage in the ReviRIS methodology, when all alternatives, criteria, and data for the IDM are clearly defined. Therefore, the questionnaire focuses on the stakeholders' preferences about ranking criteria under each topic. The results are the weights to be used on TOPSIS or SIMUS.

3. Results and Discussion: ReviRIS Decision Process for PMLU

The definition of TPMLP allows the decision-maker to structure the MCDA for a specific mine site and to be guided through the steps needed to complete the revitalization process, which is (1) environmental reclamation with engineering solutions selected; (2) revitalization stage with the theme and selection of the specific new land use; and finally, (3) the attribution of responsibilities over monitoring of the environmental reclamation work and the managing site's responsibility. These steps are defined by the formulation of four conceptual questions and their answers, which provide the following reasoning regarding the MCDA problem:

1. Questions 1 and 2 help in defining the situation of the site (static/dynamic or abandoned/inactive/active) and who takes responsibility for developing the process of mine reclamation, which, in turn, reveals a significant part: the main stakeholders involved. However, it does not mean that other stakeholders are disregarded; instead, it means that those main stakeholders are the ones going forward with the process.
2. Question 3 provides insight regarding the stage of completion of terrain modeling and implementation of engineering solutions, which, in turn, allows for the level of detail in the revitalization; and
3. Question 4 indicates that the process is at the final stage. The main reason to use this methodology, at this stage, is to determine the entities that are the final manager(s)

for the monitoring of the environmental reclamation work and the manager(s) for the new specific land use.

Considering the reasoning that these questions provide regarding the problem, the ReviRIS project develops a methodology divided into three stages (Figure 2):

- First stage—TPMLP definition and selection through the four conceptual questions already referred;
- Second stage—development of alternatives; the definition of criteria based on topics, creation of spatial, and non-spatial data by a group of experts to input into the IDM; and testing of the model using the suitable method (TOPSIS or SIMUS); and
- Third stage—a participatory process with all stakeholders involved where the alternatives and criteria are explained, and stakeholders not only attribute their preferences regarding criteria using SMARTER but also are involved in the decision process, observing the modeling result with TOPSIS or SIMUS and collaborating in its sensitivity analysis.

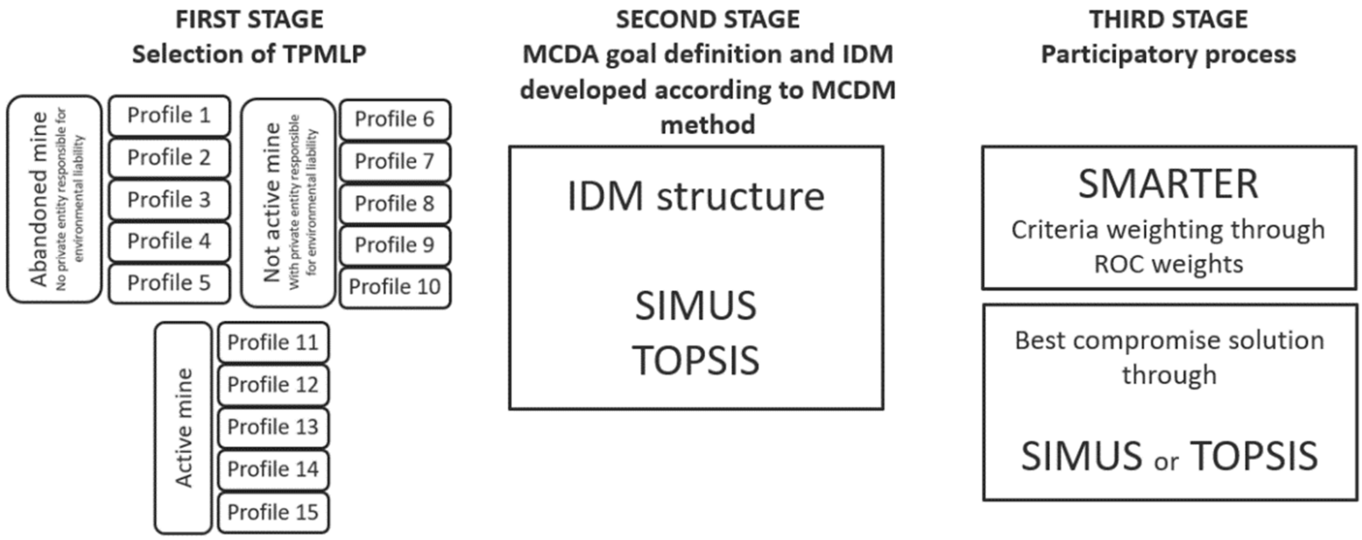

Figure 2. ReviRIS methodology for the Multi-Criteria Decision Analysis regarding a Post-Mining Land Use decision. The first stage regards the selection of the Transitional Post-Mining Landscape Profile; the second stage corresponds to the development of criteria and alternatives used to build the Initial Decision Matrix; the third stage regards the participatory process with all stakeholders.

With this structure, TPMLPs are grouped regarding their MCDA goal (Table 3) and directly linked with the answers to the questions Q1, Q2, Q3, and Q4, reflecting the steps needed to complete the revitalization process. Table 3 represents the relationship between the answers (through their TPMLP), the MCDA goal, and the suitable methods to be used.

TPMLPs 1, 6, and 11 correspond to mines without environmental reclamation fieldwork, so their MCDA goal is the engineering solution, ideally foreseeing the revitalization theme. For this, SIMUS is better than TOPSIS due to the higher level of complexity that it can handle.

For TPMLPs 2, 7, and 12, the objective is to find a revitalization theme that serves as a basis for defining new specific land-use projects after the environmental recovery fieldwork concludes. At this stage, the level of complexity is not as high as in the previous profile group; therefore, TOPSIS is suitable.

TPMLPs 3, 8, and 13 correspond to the stage after profiles 2, 7, and 12. The MCDA goal is to select the specific new land use while, at the same time, considering the future manager (for environmental monitoring control and new land use). In these TPMLPs, complex modeling is required; therefore, SIMUS is suggested.

Table 3. Relationship proposed between Transitional Post-Mining Landscape Profiles, the Multi-Criteria Decision Analysis (MCDA) goal, the methods, and the general framework of the ReviRIS MCDA tool.

TPMLP No.	MCDA Goals	Methods	Participatory Stage
1, 6, and 11	Analyze the technical solutions to be implemented in the field.	SIMUS	SMARTER for criteria's weights definition SIMUS to run the complete IDM
2, 7, and 12	Define a general objective of the future possible land use (e.g.: agriculture, natural, real-state).	TOPSIS	SMARTER for criteria's weights definition TOPSIS to run the complete IDM
3, 8, and 13	Select the specific future Post-Mining Land Use (e.g.: museum, hotel, resort, wheat plantations, corn plantations)	SIMUS	SMARTER for criteria's weights definition SIMUS to run the complete IDM
4, 9, and 14	Final responsibilities: (1) monitoring of environmental reclamation; (2) managing of the new land use	TOPSIS	SMARTER for criteria's weights definition TOPSIS to run the complete IDM
5, 10, and 15	No need to develop an MCDA	————	————

TPMLP 4, 9, and 14 make up the last group with MCDA goals. It is related to the management responsibility, either for environmental reclamation or for new land use. Once this is not a complex problem, TOPSIS is suitable for use.

Lastly, TPMLP 5, 10, and 15 do not need MCDA goals because they already have completed fieldwork for the revitalization. However, they may lack the attribution of managing and monitoring responsibilities, and in that case, they can be considered TPMLPs 4, 9, or 14.

It is suggested to use SIMUS or TOPSIS due to the scenario complexity. Once SIMUS becomes an MCDM method that can handle complex scenarios, it can be used in all MCDA goals. First, however, the decision-maker needs to learn how to use the software, which might not be feasible or necessary for less complex scenarios. Therefore, the authors suggest a more straightforward method for learning and for use with less complex MCDA goals within the ReviRis methodology: the TOPSIS method.

A complete workflow for the ReviRIS decision process is proposed in Figure 3, which links the TPMLP, MCDA goals, and stages of the methodology presented previously with GIS data integration and stakeholders' involvement. This figure summarizes the whole decision process into the following stages:

1. The first stage is the selection of the TPMLP, which consists of a simple description of the site using the four simple questions that allow for finding out which stakeholders are involved and their responsibilities. With this first step, the MCDA goal is better understood, and it is possible to start the development of alternatives.
2. For the second stage, designing alternatives, a careful analysis of the site's intrinsic characteristics (local conditions); restrictions to future new land uses; and integration with local, regional, and national spatial and non-spatial data is needed. This integration provides experts with the information needed to develop grounded and meaningful alternatives, to determine criteria that better represent the problem based on the topics, and to attribute correct performance values (data) into the IDM. After this problem structuring (MCDA stage), the situation evolves into a stage of MCDM, where a decision is needed.
3. The final stage is the participatory process involving all stakeholders and allowing them to include their preferences by attributing weights to criteria, using the SMARTER method. In the end, after an analysis of GIS features to the most relevant alternatives ranked with SIMUS or TOPSIS, all stakeholders and decision-makers are better prepared to make a decision.

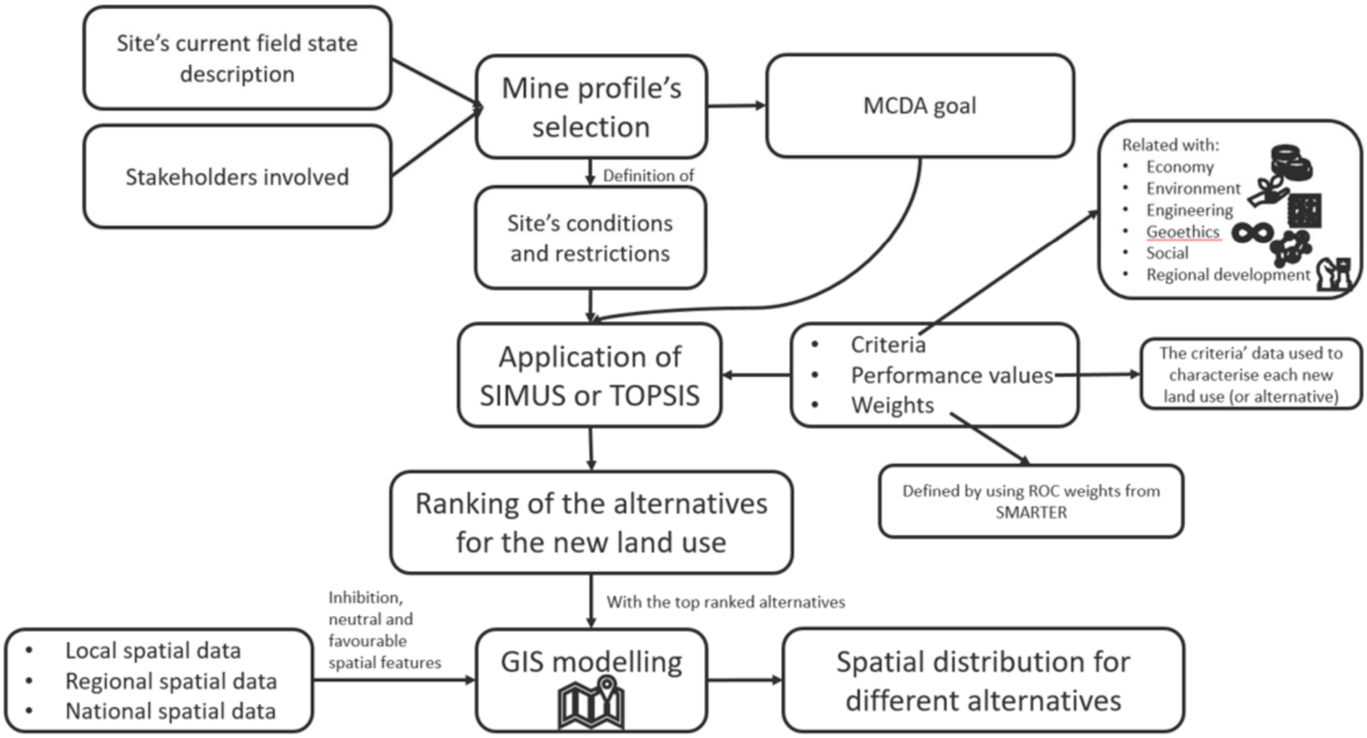

Figure 3. Representation of the overall ReviRIS methodology through a possible workflow. The workflow starts by the selection of the transitional post-mining landscape profile by describing the site and understanding which stakeholders are involved; the definition of alternatives and criteria based on topics and by using different types of data (spatial and non-spatial); and the application of SIMUS or TOPSIS to assess the alternatives with criteria's weights derived from SMARTER. In the end, a decision needs to be made to select the best compromising solution for new land use, which should consider a Geographic Information System modeling stage.

4. Conclusions

In this study, the authors presented the basis for a methodology for post-mining planning, as developed in the ReviRis project. The TPMLP corresponds to the legal state of the mine and allows for a logical and sequential process concerning the MCDA goals. Known and new topics and criteria covering all aspects related to every stage of the environmental reclamation and revitalization of mineral exploitation areas were included in the decision process. Consequently, the methodology leads to better and grounded alternatives, which helps in decision-making in post-mining land use planning. The modeling approach was also developed to include results derived from public participatory processes. Further work involves methodology and model verification using case studies of different TPMLPs.

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