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Establishment of multiple conflicting criteria in decision making processes to support revitalization of transitional and post-mining regions

Dissertação para obtenção do Grau de Mestre em Engenharia Geológica

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To my father,

who I know would be proud

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Abstract

The mining industry not only plays a very significant role in the modern society, as it allows the access to mineral resources, but has been also fundamental throughout Human History. However, there have been situations, especially in the past centuries, for which an adequate plan has not been considered to ensure adequate mine closure processes. In some cases, mines became abandoned, which brings strong negative impacts to the surrounding environment, the development of the regions and even to local communities.

This dissertation was developed with the support of the EIT Project Reference 19075 "ReviRis: Revitalising Post-Mining Regions: Problems and Potential in RIS Europe" and its main objective consisted in establishing criteria and indicators to be considered in the rehabilitation of post-mining regions and in its supporting multi-criteria decision-analysis (MCDA) processes. MCDA is a valuable tool applicable to solve problems that are characterized as a choice among alternatives. In the present context, the aim of MCDA processes is to select the best rehabilitation option to be implemented in a specific mining area after its closure according to its site specificities.

The selection of a post-mining land use considers a large amount of information that needs to be compared to reach a final decision. This information comes in different forms and is related with different subjects. Several MCDA methods have been developed. The general concept is closely the same: evaluate possible alternatives for a certain problem based on selected criteria. In most of the methods a weight (a relative importance) for each criterion is considered. In this study, five criteria groups were developed: economic, environmental, geoethical, technical and potential regional development. These criteria groups were then sub-divided in lower levels of more detail to allow a more precise evaluation. To test the established criteria and sub-criteria, distinct MCDA methods were applied to a Portuguese mining site - Urgeiriça. The results highlight the differences between distinct methods and show how the criteria weights play a very relevant role in the results, evidencing that the usage and management of the available information is crucial in problems of this type.

Keywords: Mult-Criteria Decision Analysis, mine closure, MCDA criteria weighting, post-mining land use and revitalization

Resumo

A indústria mineira não só desempenha um papel muito significativo na sociedade moderna dado que permite o acesso aos recursos minerais, mas também é uma atividade crucial em todos os períodos da história da Humanidade. No entanto, têm surgido situações, sobretudo nos últimos séculos, em que não foi considerado um planeamento adequado que assegure um fecho da mina apropriado. Em alguns casos, as minas ficam abandonadas, o que traz impactes negativos fortes para o ambiente envolvente, o desenvolvimento da região e até para as comunidade locais.

Esta dissertação foi desenvolvida no âmbito do EIT Project Reference 19075 "ReviRis: Revitalising Post-Mining Regions: Problems and Potential in RIS Europe" e o seu foco principal consiste em estabelecer critérios e indicadores a considerar na reabilitação de regiões *post-mining* (antigas regiões mineiras) para subsequente aplicação de métodos de análise multi-critério de apoio à decisão (MCDA). MDCA é uma ferramenta útil na resolução de problemas caracterizados como uma escolha entre várias alternativas. No presente contexto, o objetivo principal associado á aplicação destes método é o de selecionar a melhor opção (ou melhores opções) de reabilitação a ser implementada numa área mineira específica, após o seu fecho de acordo com as condições e características do local.

A seleção de um uso do solo *post-mining* tem em conta uma grande quantidade de informação que necessita de ser comparada de modo a alcançar uma decisão final. Esta informação assume diferentes formas e está relacionado com diferentes tópicos. Muitos métodos MCDA têm sido desenvolvidos. O conceito geral é normalmente muito semelhante: avaliação das alternativas possíveis para um determinado problema tendo por base critérios previamente estabelecidos. Na maioria destes métodos é considerado um peso (uma importância relativa) para cada critério considerado. Neste trabalho, foram desenvolvidos cinco grupos de critérios: económico, ambiental, geoético, técnico e desenvolvimento regional potencial. Estes grupos foram depois subdivididos em níveis menores de maior detalhe permitindo uma avaliação mais precisa. De modo a testar os critérios e subcritérios estabelecidos, foram aplicados diferentes métodos MCDA numa mina portuguesa – Urgeiriça. Os resultados realçam as diferenças entre os métodos distintos e mostram como os pesos dos critérios desempenham um papel de elevada relevância nos resultados finais, evidenciando que o uso e a gestão da informação disponível é crucial em problemas deste tipo.

Palavras-chave: Análise Multi-Critério de Apoio à Decisão, planos de fecho da mina, ponderação de critérios, Revitalização e ocupação e uso do solo após a exploração mineira

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1. Introduction

1.1. Framework

The mining activity plays a big role in the world's economy and it's one of the most important activities in the resources and energy sector, but its very nature disturbs the land and has very significant impact on the landscape of the region as well as on the land use, especially after its closure. Several environmental and safety problems are raised by abandoned mines, mostly due to poor mine waste management and altered topography[1]. Many of the mines that represent a problem nowadays started their activity decades ago, when modern environmental laws weren't established, which means that they were usually developed without considering a reclamation plan to be applied in the future after the mine's closure, which resulted in even bigger and more complex revitalization problems.

The mining industry has played a critical role in the history of many European nations, forming the basis of their economic and social identity and 'fabric', let alone their development over the centuries. With World War II, the focus on obtaining resources for weapons and machinery become a critical factor of advantage and a big opportunity to boost the economy, contributing for the advance of the industry. However the influence of the market place over mining was a very strong one and the only concern was the economic wealth, and as reserves are exhausted or market conditions change, a number of unavoidable socio-economic and considerable environmental degradation can occur. Abandoned and insecure surface and underground mines, facilities, lowered or contaminated groundwater and contaminated sites are just some of the examples of consequences associated with the mining activity when there's not reclamation plan. Regions affected by this suffer at different levels: the surrounding environment is contaminated; imbalances in the ecosystems; the usage of land is compromised, because the mine facilities are still there not being used, which doesn't give room for other activities to grow; the population density can drastically decrease after the closure of the mine; and the population will be unhappy. The "moon landscape" of abandoned mines is one of the most commonly used arguments by opponents of developing new mineral deposits and why post-mining revitalization is important to gather social acceptance, and ultimately access to future mineral deposits.

Traditional reclamation practices have been, in the case of formally rehabilitated sites, to return the land to as much of an original condition as possible. In cases of abandoned or mine sites that received minimal or no formal rehabilitation efforts, this becomes more problematic. The locally affected community has the closest attachment to these landscapes and it is their best interest to be part of the decision-making process; one that considers the social, economic and biophysical implications of any closure and rehabilitation plan. For example, the local community may want to retain some of the man-made aspects of the mine site (e.g. pits or waste dumps) for their aesthetic or recreational value and to promote tourism as secondary land use. The key is the active participation and the extension of the Social Licence to Operate through mine closure and site rehabilitation and for them to play an active role in the ultimate post-mining landscape and land use. In the context of this proposal, REVITALISATION is understood as both rehabilitations making the area environmentally safe and socio-economic renewal. Taking this into account, also the potential of post-mining areas (e.g. heritage, flooded excavations, geological phenomena) should be better used for regional and local identity and further socio-economic development (ReviRIS).

The toolkit that will be developed in this thesis will take into account, not only the environmental but also the economic, societal and geoethical aspects of mined sites. It intends to constitute a forward step on mining rehabilitation and allow users and stakeholders to identify the best possibilities and alternatives for site revitalization and former mine-land valorisation.

1.2. Objectives

The present thesis is inserted in the Project "ReviRis: Revitalising Post-Mining Regions: Problems and Potential in RIS Europe". This project consists in an evaluative toolbox for decision-makers. The project contextualizes current practices in civic engagement and decision-making focusing on involvement, and engagement of different actors and stakeholders in the planning/design process in the revitalization of post-mining land. The evaluative criteria are based on social, economic and biophysical attributes, possibilities and constraints, and tested using RIS region example cases.

The impact from the application of the toolkit can also be demonstrated in better and more integrated land-use considering site-specific characteristics, necessities, potentialities and also constraints. Each can be evaluated in terms that ensure feasible future land revitalization of mining or transitional sites. In this context, this project will have an impact through: (1) the identification of the environmental, economic, social and geoethical factors as the key-indicators to be considered in the evaluation of rehabilitation and revitalization of transitional sites (2) the achievement of a better understanding of how these factors and key-indicators may vary according to regional and local site specificities, considering real examples as distinct case-studies (3) the verification of the possibilities to integrate and ponder the selected key-indicators in a toolkit with the potential to be applicable in distinct regional contexts (4) to achieve feasible and reliable solutions for future land revitalization in mining projects (5) to promote and enhance social acceptance towards mining activity and its possibilities regarding land regeneration and revitalization, and new land occupational opportunities (6) to promote economic potentialities and better valorisation of “mining land” or “transitional land occupational sites”. With the toolkit, it will be possible to develop a perspective of the possibility of enhancing and enhancing the value of the “Post-mining landscapes” in a measurable way. Guidelines for these types of processes will be generated with the inclusion and part of the public assessment. This will enhance the reliability and public acceptance in future “post-mining” projects. It is intended to have the contribution of relevant stakeholders involved in the process of mine decommissioning and closure and in the development of this toolkit. As a result, it is expected that the development of a tool kit with real impact that can be used effectively in future mine closure projects. The economic benefit is also expected to be realized once land and its environmental regeneration possibilities are revealed in a balanced, feasible and reliable process. Inevitable impact in societal terms will be derived from the inclusion of SLO/A indicators in the toolkit to be developed. This will represent an advanced step forward for post-mining processes once social acceptance is better oriented and integrated relatively to mining site specificities, it’s possible alternatives and constraints. It is expected that this project may represent an effective and genuine contribution to the rapprochement of the mining sector with wider society, though more balanced and effective land regeneration and revitalization processes. Sustainability of future mining sites will be also enforced.

The objective of this project is to develop models and an evaluative ‘toolbox’ for regional decision makers (regional and local governments, industry and communities). The scope of the project is to develop an evaluative decision-making scheme for transitional and post-mining lands based on a) local stakeholder’s needs, b) needs of land-use planners and regional developers (planners and public administration), c) range of possibilities for alternate land use, and d) social, economic, cultural, as well as environmental attributes of a given site.

The project is divided in seven Work Packages (WP). This thesis addresses two of the seven WP, these being:

- WP3: Definition of site evaluation criteria and indicators
- WP5: Development of a toolkit for stakeholders

The main objectives of the thesis are defined based on WP3 and WP5. The first objective is the establishment of criteria to integrate in a multi-criteria analysis of transitional and post-mining regions. It is established the analytical and spatial data to be considered and integrated respectively in the multi-criteria decision-making (MCDM) toolkit. Appropriate weighting and multi-criteria decision-making methods is developed considering the profile and type of transitional area to be evaluated. The selection of most viable distinct multi-criteria techniques and methodologies in order to include uncertainty and risk in the decision support toolkit and to allow the stakeholder to explore its viewpoints is explored. The second goal is the selection of a post-mining land use for a specific mining region, by using the tools explored in the previous objective. In this phase, site-specific data is collected and then integrated in a multi-criteria model in order to establish a site-specific matrix, allowing the evaluation of the different alternatives that are being considered to that mine region, so that a rehabilitation plan can be implemented. After the results, it is possible to do an assessment about the robustness of the multi-criteria tools when applied in this type of scenarios.

1.3. Chapters

The first and present chapter is introductory. Its finality is to make an introduction about the dissertation subjects, exposing the background and referring the objectives and aims of the study. Additionally is presented the structure of this work by describing the chapters that constitute the latter and stating the topic approached in each one.

Chapter 2 is related with Multi-Criteria Decision Making (MCDM) or Multi-Criteria Decision Analysis (MCDA). Here is explained what is MCDM and the reasons for the use of this process in several fields. After this, every step of the process is described. Then, the types of MCDM and weighting methods are referred. The most commonly used techniques are summarized in this chapter too, highlighting their main features and unveiling a bit of their "black-boxes". Finally, is showed a comparison between the different methods, analysing their advantages and weaknesses.

Chapter 3 addresses the indicators of post-mining regions to be used as criteria in an MCDM model to apply in Portuguese mines, where the scope is selecting the best post-mining land use. The main objective is to establish different kinds of criteria so that those mines (the alternatives) can be compared between themselves. There's a lot to consider when talking about post-mining land use, since there are many factors to be taken into account such as: economy, environment, geoethics, technical and engineering solutions and development of the region. Those five main topics are then divided in several sub-branches, where each one of them is described and a classification suggestion is proposed.

Chapter 4 presents the case study in a Portuguese mine – Urgeiriça. The chapter starts with a brief description of the mining area followed by definition of the performance matrix established for this specific mine. Next are showed the various scenarios considered concerning the weights of criteria and then the results are presented , commented and discussed.

Chapter 5 is the final chapter of this thesis and it is where the final considerations are made as well as suggestions for future works related with the topic of the dissertation.

2. Multi-Criteria Decision Making

2.1. Introduction to Multi-Criteria Decision Making

Everyday people are exposed to situations where they have to choose between two or more alternatives in order to obtain the best value for a certain purpose or objective. It could be simple things like deciding which pair of shoes to wear or what cereals to buy. Sometimes, the decision gets more complicated involving more factors to consider; for example, the purchase of a house or a car. And in other cases, the complexity of the problem requires tools to aid in the decision making process, due to large number of possible alternatives and attributes that are relevant to the problem, often with conflicting objectives that decision makers value differently. An example for this kind of more complex situations would be the decision of where to build a new airport.

The process of selecting a possible course of action considering all the available alternatives is called decision making. The multiplicity of criteria for judging the alternatives is inevitable in almost every cases. The decision maker pretends to achieve one or more goal or objective by selecting the course of action while satisfying the constraints imposed by processes, resources and environment.

The Multi-Criteria Decision Making (MCDM) or Multi-Criteria Decision Analysis (MCDA) establishes preferences between options by reference to an explicit set of objectives that the decision making body has identified, and for which it has established measurable criteria to assess the extent to which the objectives have been achieved[2]. The basic idea of MCDM methods is to evaluate the performance of alternative courses of action with respect to criteria that capture the key dimensions of the decision making problem (e.g. ecological, economic, social sustainability), involving human judgment and preferences[3]. So, decision making is complex process of selecting criteria, then determining alternatives and finally gathering evaluations and processing information. All of the information used in the process should be considered and adjusted towards the objective of the MCDM.

MCDM is used as an interface between stakeholders/decision makers and analysts in the several fields, aiding them in reaching a decision when there is the evolvement of multiple and often conflicting criteria. MCDM is concerned with supporting decision makers who are faced with numerous and conflicting alternatives to make the best decision.

2.2. Steps of Multi-Criteria Decision Making

MCDM is a step-by-step process. Some of those steps require a detailed thought about the subjects that affect the decision. Sometimes the need to re-visit earlier steps can arise, as well as the need to reevaluate them. This process follows the following stages (illustrated in Figure 2.1):

Step 1: Defining the objective(s):

The beginning of the process usually consists in the definition of the problem. To have a clear understanding of the objectives is crucial for the process. The decision context involves all sort of factors: economic, social, environmental, etc. Nonetheless, the decision making body and those who are responsible for the decision (such as stakeholders, experts and politicians), as well as the set of people who may be affected by the decision, represent a central part of the problem. So, it is important to identify the main purpose to be achieved with this decision; what is the fundamental objective? And how can it be divided in different sub-objectives?

According to Roy[4], decision problems can be classified in four types:

- *Choice problem:* select the best option or reduce to options to a group of equivalent or incomparable good options.
- *Sorting problem:* sort the options into ordered or predefined with similar behaviors or characteristics (categories).
- *Ranking problem:* the options are ordered from best to worst by means of scores or pairwise comparisons, for example. This order can be complete or partial (in cases where there are incomparable options).
- *Description problem:* describe options and their consequences.

Given these types of decision problems and the involvement of several criteria, the complexity of decision making is high. For that reason, there's the need to apply certain methods and techniques to structure the decision making process.

Step 2: Identify the options

The next step is to determine the alternatives that can potentially satisfy the problem. They must represent a feasible and suitable solution to the problem, considering all factors and restrictions.

Step 3: Identify the criteria and sub-criteria

To assess the options, it is necessary to think about the consequences that the decision will entail. Consequences differ in many ways, and those ways

that matter because they achieve objectives are referred to as criteria. A criterion is an attribute associated to each action that makes it possible to compare the actions and to determine the best ones. They can be quantitative, qualitative or mixed. Criteria express the many ways that options create value.

Step 4: Scoring (performance matrix)

A scoring system must be chosen in order to evaluate the performance of each alternative regarding each criterion, by assigning values to each alternative. This will generate a matrix as shown in Table 2.1. The information that is inserted in this matrix can be quantitative, qualitative or even mixed. Different kind of data can't be combined. A cost is represented by a number that can vary between 0 and infinite (theoretically speaking), the quality of a product can be represented by a scale, which as an upper and lower threshold, and the presence of a specific feature is represented by a "Yes" or a "No". In order to compare all these values, it is necessary to apply a normalization technique.

Step 5: Weighting

Weighting allows the decision maker to establish a preference degree over one criteria over another, since each criteria is likely to have different relative importance in the context of the problem that is being faced, which means that different criteria may carry different weights

Table 2.1 Performance matrix (Adpated from survey of applications of multicriteria decision analysis methods in mine planning and related case studies, Musingwini, 2010

		Criteria					
		C_1	C_2	....	C_j	....	C_n
Alternatives	A_1	O_{11}					
	A_2		O_{22}				
	....			....			
	A_i				O_{ij}		
	....					.....	
	A_m						O_{ij}

Step 6: Calculation of overall weighted scores

Combining the scores and weights using a specific set of calculations.

Step 7: Examine the results

The results can be displayed in various forms depending on what technique was used and it is important to choose an adequate to way to visualize them.

Step 8: Sensitivity Analysis

Caers[5] states that a sensitivity analysis aims to evaluate the impact of varying some "input parameters" on some "output response". Assessing the impact of changes in the weights is an important procedure in the decision making process. In sensitivity analysis the most important things it's not establishing or estimating the absolute values, but instead trying to understand what causes the most impact in such values[5].

Step 9: Final Decision

When all the previous are completed, the decision maker have the all the necessary information to make a final decision. So, the final decision that we typically get after applying MCDM techniques or MCDM methods, they may not be the best possible one, but they are of course going to be one that is acceptable to all the stakeholders. So, if there are more than one decision makers, so that consensus has to be reached. So, the solution, the final decision, has to be accepted to all the stakeholders, who typically are identified in the very first step when we are trying to understand the problem.

When multiple decision makers are involved, conflicts need to be handled because the subjective preferences of different decision makers could be different. Therefore, we need to reach a consensus so that a final decision could be made. So decision makers often base their decision on subjective judgments. So, subjective judgments are taken in consideration, and typically based on the subjective judgments of decision makers, the final decision is made.

The described step-by-step process is schematically summarized in Figure 2.1. As the figures suggests, the process can be divided in three main groups (the three circles on the left):

A. Problem structuring: where all data is collected and managed, according to the specificities of the problem, so it can be defined. Steps 1 to 3 are included here.
B. Model building: this phase consists in the application of the MCDM model, with the integration of the data from the previous steps. Steps 4 to 6 are included here.
C. Using the model to inform and challenge thinking: after the results are obtained it is time to evaluate them and identify a solution based on the rankings/scores. Steps 7 to 9 are included here.

Identifying the problem is the starting point of the process and developing an action plan is what finishes it.

The grey descending arrows indicate the "direction" of the process, this is, the order of the steps/phases. However, blue arrows can be seen in the opposing direction. These represent the constant adjustments that could (and should) be made along the process in order to improve it and consequently obtain better results.

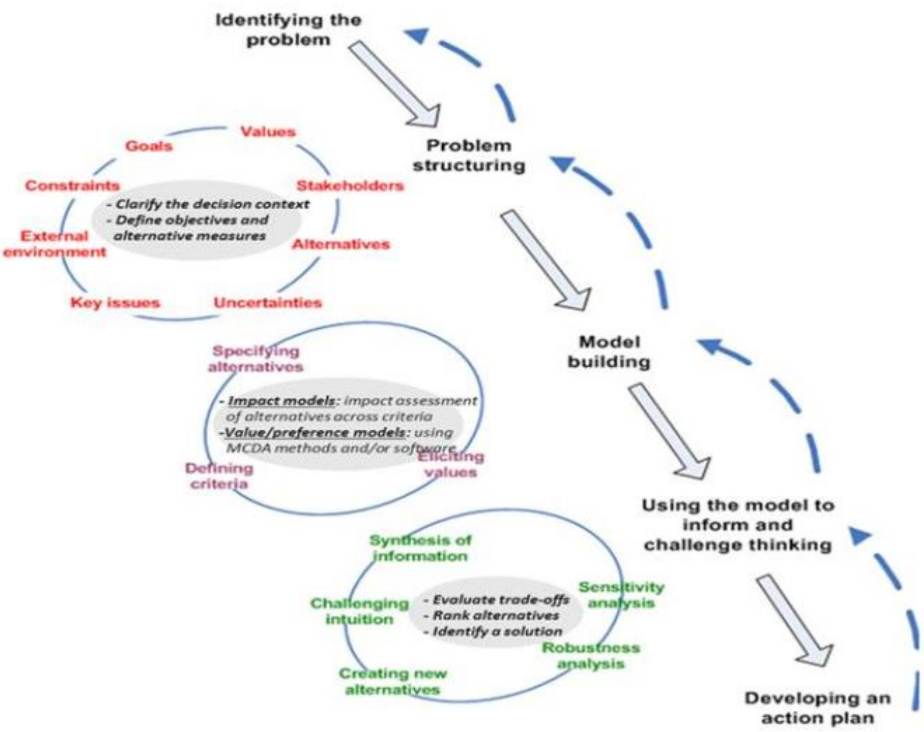

Figure 2.1 An illustration of the MCDM process in Catrinu-Renström et al.(2013), modified from Belton and Stewart (2002)

2.3. MCDM Methods

According to Saarikoski[3], MCDM methods are integrative evaluative methods, since they combine information concerning the performance of the alternatives with respect to the criteria involved, and with subjective judgements about the relative importance of each criteria regarding the specific context of the decision making. The main role of this techniques is to handle large amounts of complex information in a consistent way, something that proved to be very difficult to human decision makers. Supporting the decision making process does not necessarily mean than one option will be identified as the best or most preferred alternative. That is one of the possible outcomes, however MCDM techniques can also provide a ranking of the options, short-listing limited option for subsequent detailed evaluation or even select acceptable options from unacceptable ones.

The role of MCDM methods has been increasing over the last decades, in different fields of application, and as a consequence several methods were created and old methods were improved. The constant progression of technology allowed for the development of more complex decisions making techniques that can be used to solve real world problems.

There are two main groups. The first one is the Multi-Attribute Decision Making (MADM) and the other is the Multi-Objective Decision Making (MODM). The focus on MADM are problems with discrete decision spaces, while MODM involves several conflicting objectives that need to be optimized at the same time. From a practical point view, MADM is related with situations with where there is a finite and predetermined number of alternatives, selected by the decision maker or stakeholders. On the other hand, MODM is associated with problems where the alternatives have been not pre-determined. In this thesis, the focus will fall upon MADM methods, since the problems that are being faced contemplate a determined number of alternatives.

This work will analyze the most commonly used MCDM (in the MADM group) and weighting methods. These methods can be divided in three fundamental groups based on their approach:

<u>Full aggregation</u>

A score is evaluated for each criterion and then synthesized into a global score. This kind of approach admits compensable scores, where a bad score in one criterion can be compensated by a good score on a different criterion[6]. Those scores allow each alternative to be comparable with another. They are expressed while taking into consideration the performance of the alternatives according to the criteria and sub-criteria selected for the analysis[7].

This group includes: **AHP, ANP, MAUT, MACBETH**

Outranking methods

Outranking indicates the degree of dominance of one alternative over another. These methods enable the utilization of incomplete value information. They are based on pairwise comparisons and they provide the partial or complete ranking of the different alternatives. They are commonly used when facing complex situations with multiple criteria and multiple participants. In these methods there is no need to assume the existence of a utility function or some other functional form. What matters is, whether the available information is enough to assert that option A is at least as good as option B.

In outranking methods, thresholds models are applied to the original criteria value, so it is treated as pseudo-criteria, and two thresholds are defined: preference and indifference.

The preference (p) is measured as a way in which the decision maker knows exactly what to choose between two alternatives based on criteria previously established. It represents the difference above which the decision maker strongly prefers option A over option B. Considering P_A, the performance of option A and P_B, the performance of option B, A is preferable to B if:

$$A \mathbf{P} B \iff P_A - P_B > p \; (1)$$

Indifference (q) refers to the situations where the decision maker can´t define an absolute preference regarding two options. In those cases, it is said that the decision maker is indifferent to both options, since each of those options brings the same degree of benefit or satisfaction:

$$A \mathbf{I} B \iff |P_A - P_B| \leq q \; (2)$$

In some cases, there is a zone between these two thresholds called zone of weak preference, where the decision maker hesitates between strong preference and indifference, and it's defined by:

$$A\ \mathbf{Q}\ B \iff \mathrm{q} < P_A - P_B < p \ (3)$$

There's also the possibility of incomparability between two alternatives, given the fact that they can have different profiles, i.e., alternative A can perform well under a certain set of criteria, whilst alternative B can be better based on another set of criteria. This makes it difficult to compare them, so a complete ranking is not always possible, and thus emerges the necessity of the partial ranking. The incomparability is a result of the non-compensatory aspect of these methods, where a bad score may not be compensated by a better one[6].

This group includes: **PROMETHEE, ELECTRE**

Goal, aspiration or reference level

Definition of a goal for each criterion and posteriorly identify the closest option to the ideal goal or reference level. The options are evaluated using the aggregate collection (vector sum) of the performance in relation to the different criteria that allow one to define how far (vector) the alternatives fall from the objective[7].

This group includes: **TOPSIS, VIKOR, Goal Programming**

Figure 2.2 summarizes the MCDA methods considered in this thesis.

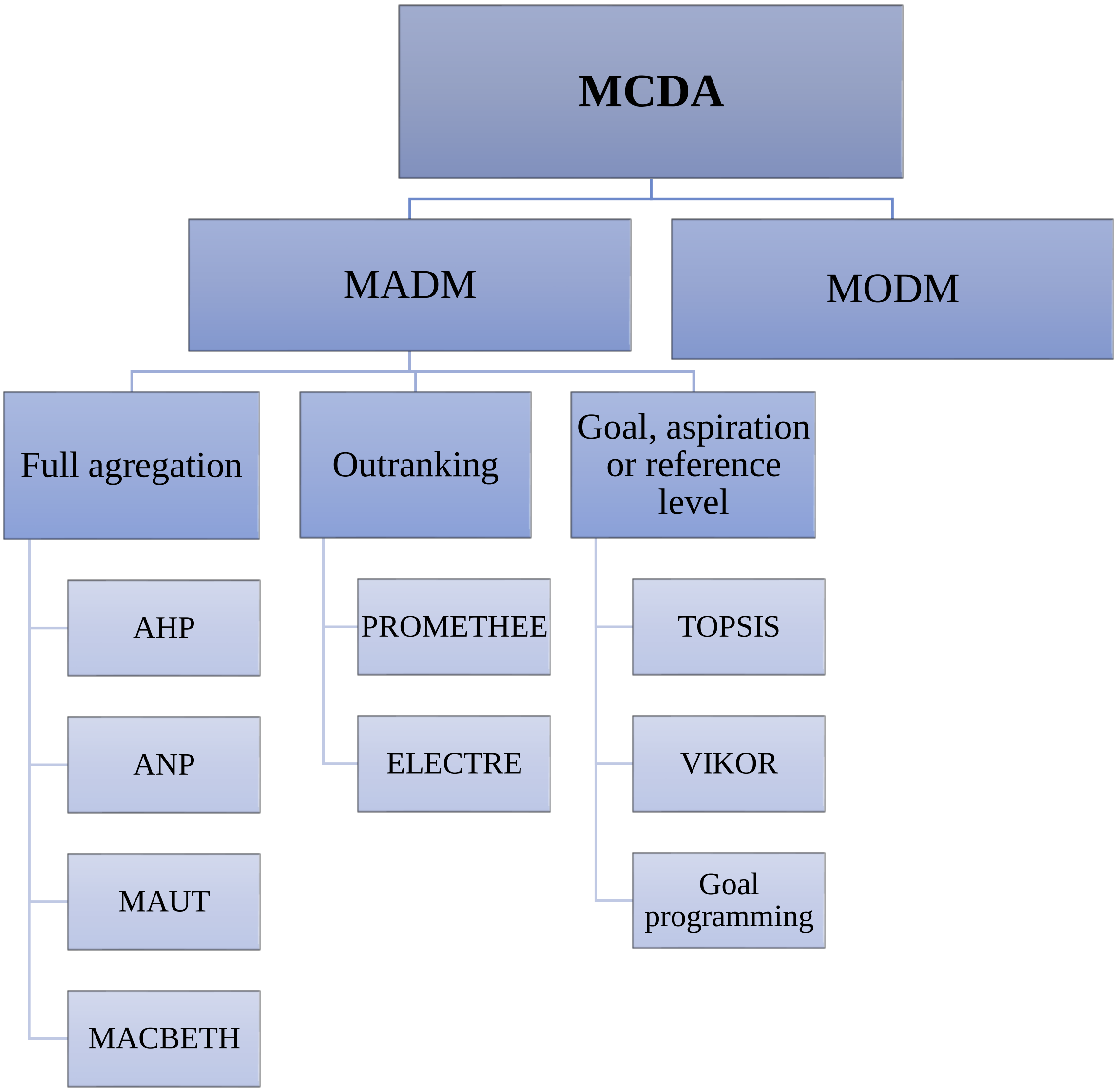

Figure 2.2 MCDA methods

2.3.1. AHP

AHP stands for Analytic Hierarchy Process, and is arguably the most commonly used method in MCDA. Its main purpose is to prioritize alternatives based on criteria. For this, pairwise comparisons based on a ratio scale (A/B) are used. It allows some small inconsistency in judgement.

After the objective is defined, the problem is structured according to a hierarchy, where the top level refers to the goal. The second level represent the criteria and the last level are the alternatives. There are a minimum of three levels in this hierarchy, however more levels can be added between the second and last level, representing the sub-criteria. A representation of the hierarchy is showed below on Figure 2.2.

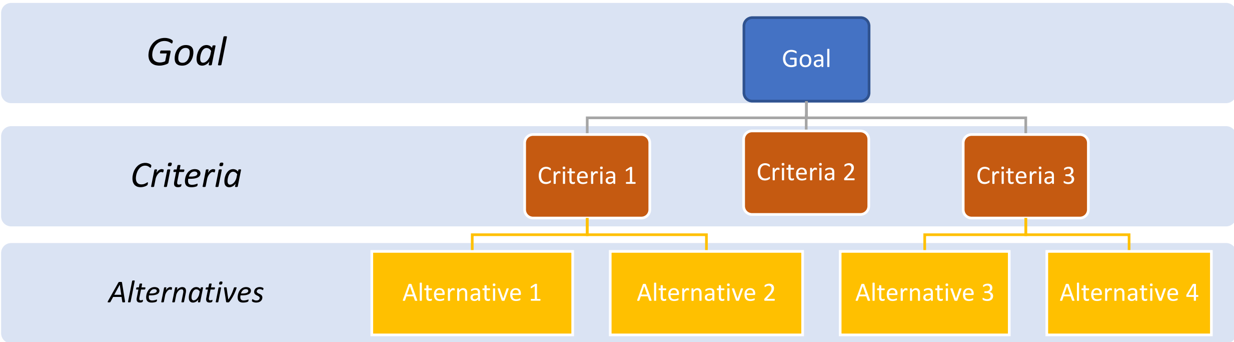

Figure 2.3 Representation of the hierarchy

The next step is the priority calculations. A priority is the importance of an alternative or criterion in the decision[6]. There are three type of priorities:

- **Criteria priorities**: importance of each criterion with respect to the goal, representing the weight of each criterion.
- **Local alternative priorities**: importance of one alternative with respect to one specific criterion.
- **Global alternative criterion**: calculated using the other priority types, generating a ranking of the alternatives with respect to all the criteria and subsequently to the goal.

Both criteria and local alternative priorities are calculated using the same technique, which consists in pairwise comparisons, where entities are compared in pairs in order to judge which one is more preferred. Psychologists argue that is easier and more accurate to determine the preference of alternatives if compared between only two alternatives at a time, than by comparing them all simultaneously. Pairwise comparisons are usually evaluated on the fundamental 1-9 scale, showed in Table 2.2. These comparisons are then collected into a matrix.

Table 2.2 Scale of relative importance

Degree of importance	Definition
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance

If alternative A is strongly more important than alternative B, the value that represents that comparison is 5. In opposition, instead of comparing A to B, if comparing B to A, the reciprocal value is obtained, which in this case would be 1/5. Although there are only odd numbers on the scale, the comparisons can also assume even numbers, such as 2,4,6 or 8, if referring to intermediate values. For example, 2 represents weak importance, since is bigger than 1 (equal importance) but lower than 3 (moderate importance).

An example of a comparison matrix is displayed below on Table 2.3. This specific matrix gathers the information of pairwise comparisons between the criteria.

Table 2.3 Comparison Matrix

	Criterion 1	Criterion 2	Criterion 3
Criterion 1	1	3	5
Criterion 2	1/3	1	9
Criterion 3	1/5	1/9	1

All the values on the diagonal of the matrix are 1 because a criterion is being compared to itself, so the relative importance has to be 1. Comparison matrices are always reciprocal, since the upper triangle is the reverse of the lower triangle. The number of required comparisons for each matrix is given by:

$$\frac{n^2 - n}{2}$$

where n is the number of alternatives/criteria. This means that adding more alternatives/criteria to the problem will imply a great increase of necessary comparisons. When the matrix is complete, a consistency check should be executed to detect possible contradictions, since several consecutive pairwise comparisons were made.

With all matrices completed, the normalized principal eigenvector of each matrix is computed and using additive aggregation the global scores can be obtained. This scores will provide a final ranking of all alternatives from best to worst regarding all criteria. In the end, a sensitivity analysis can be performed.

2.3.2. ANP

The Analytic Network Process (ANP) is a generalization of the AHP method. It can model complex decision problems, where a hierarchical approach such as AHP is not sufficient. ANP allows for feedback connections and loops and incorporates the AHP. Most of the methods that will be described, being AHP one of them, considers criteria to be independent. But if they are not independent, overvalued weight can occur due to correlated criteria. ANP allows these dependencies to be modelled; they are closer to reality and, as result, yield more accurate results[6].

In AHP, pairwise comparisons are made, in order to get local priorities and weighting factors, and posteriorly global priorities are calculated, creating a ranking of the alternatives with respect to the criteria. It is a top-down structure, starting on the goal, down to criteria (and sub-criteria) and finishing in the alternatives. On the other hand, in ANP criteria and alternatives are treated equally as nodes in a network, demonstrated in Figure 2.3. These nodes might be compared to any other node as long as there is a relation between them. Alternatives can influence the

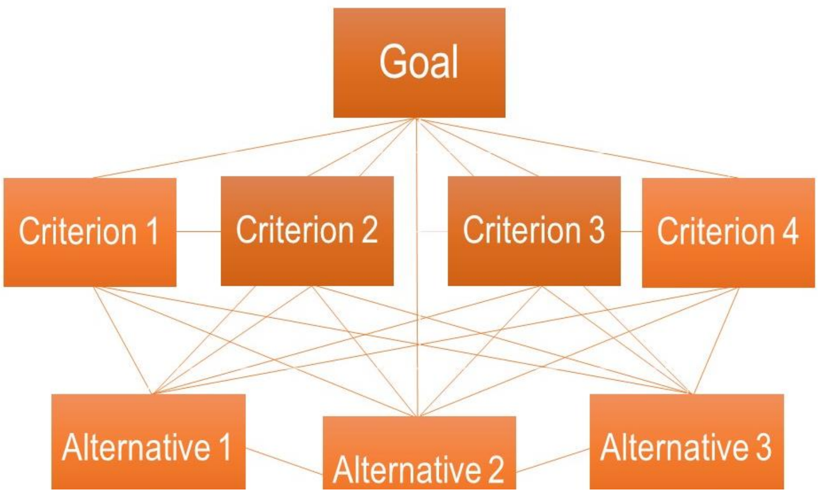

Figure 2.4 ANP network

ranking of criteria, so the weightings are not the only factor on which the ranking depends, making it no longer a top-down structure.

In contrast to AHP, where there are levels of hierarchy and the top-levels connect to lower ones, in ANP nodes can be grouped in clusters. Beside local priorities in the comparison of one node to a set of other nodes, cluster priorities (with respect to the goal) can also be included.

ANP contemplates three types of dependencies:

- **Inner dependency in the criteria cluster**: correlation between elements of the same criteria cluster.
- **Inner dependency in the alternative cluster**: correlation between elements of the same alternative cluster.
- **Outer dependency**: correlation between two clusters (also called feedback).

The influence of each node on other nodes in a network can be gathered in a super matrix[8]. The super matrix is composed by listing all nodes horizontally and vertically, as shown in Table 2.4, and sets out the influence of the three (main) clusters: goal, criteria and alternatives. If there are no dependencies between two nodes, a zero is entered. Each non-zero element of the matrix represents the connection and weight from one node of the network to another one.

Table 2.4 Super matrix

		Goal	Criteria				Alternatives		
			C1	C2	C3	C4	A1	A2	A3
Goal		0	0	0	0	0	0	0	0
Criteria	C1	Weight of the criteria	Eigenvector of influence on each criteria (because of inner dependency on criteria cluster)				0	0	0
	C2						0	0	0
	C3						0	0	0
	C4						0	0	0
Alternatives	A1	0	Local priority of alternative A_i with regard to criteria C_i				Eigenvector of influence on each alternative (because of inner dependency on alternative cluster)		
	A2	0							
	A3	0							

The green area in the super matrix is what we usually have in the AHP method, as well as the information on the yellow area. Red zones represent inner dependencies. The super matrix displayed on Table 2.4 has no outer dependency from the alternative to the criteria, so the grey zone it's just zeros. If that outer dependency existed, then the cluster goal would be removed (meaning that the first row and first column would disappear) and the grey zone would represent the weight of criteria with regard to each alternative. The comparisons of nodes follow the same principle as AHP, therefore the local priorities will result from the eigenvector of comparison matrix, and then arranged as column vectors in the super matrix. After all comparisons are made, the matrix must be normalized to 1, in order to have stochastic matrix that can be used in a Markov chain process. The whole mode is synthesized by calculating the Limit Matrix. The Limit Matrix is the result of the super matrix (normalized) taken to the power of k+1, where k is an arbitrary number, converging into a matrix where the value stabilized, which contains the global priorities.

2.3.3. MAUT

The multi-attribute utility theory (MAUT[1]) is based on the main hypothesis that every decision maker tries to optimize, consciously or implicitly, a function which aggregates all their point of view[6] – the utility function. In the beginning of the process this function may or not be known, so the decision maker might need to define it. The utility function expresses a person's preference regarding different levels of an attribute, dealing with uncertainty (through probabilities and expectations). If an utility function can be constructed, this method is usually recommended over AHP.

The MAUT methodology ranks alternatives based on the overall utility. In order to choose between several alternatives, the global utilities of the available alternatives must be measured so a decision can be made. To assess the utility of an alternative it is necessary to consider several criteria. Each criterion will have an associated score, called the marginal utility score obtained from a marginal utility function (Figure 2.5). Usually these functions are crescent, because normally the goal is to maximize (bigger area of a house, higher score; or better taste of food, higher score). But sometimes it can have decreasing functions, when the goal is to minimize (the price

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[1] *<u>NOTE</u>: MAVT (multi-attribute value theory) is a very similar method to MAUT, however it operates under certainty, while MAUT considers uncertainty. For that reason, MAUT is the method to be considered in this work.*

or cost is the most obvious example). To determine the utility value for a particular alternative is typically used utility functions that are derived and they are used to determine the score for decision makers' preferences.

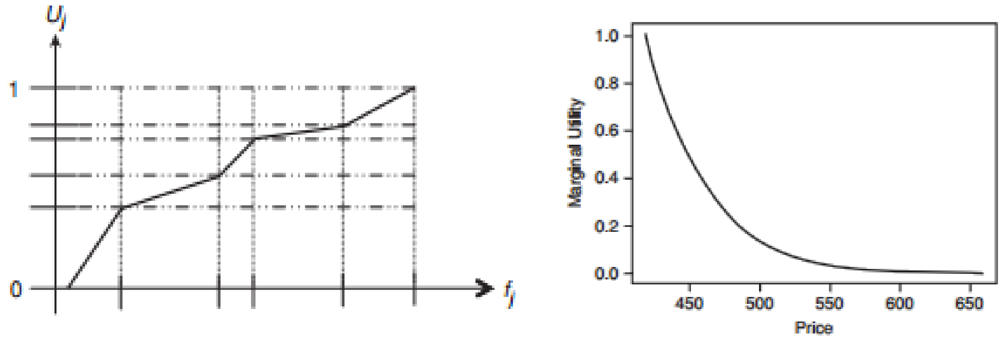


Figure 2.5 Utility functions

The utility function can be described as a numerical representation of the decision makers' preferences on the set of alternatives. Many times this numerical representation is quite difficult to specify and that becomes a drawback of this particular method, i.e. value- based theories. Another problem is the unrealistic assumption of preferential independence. This is another drawback of value-based theories because in this particular theory, it is assume that the alternatives and the criteria are independent which might not be realistic.

Another point is that empirical difficulties could be experienced with the utility function in handling practical problems. As it was said before, utility function could be very difficult to specify, and because of this, practical challenges in terms of using the approaches or methods under value-based theories might be faced.

In a more advanced phase of the process, the marginal utility scores will be aggregated in the overall utility score. The most common method of aggregation is the additive model, however other models like the multiplicative or multilinear can also be used. The overall utility score will permit a ranking of the alternatives from best to worst.

- If option A has a better score than option B, then A is preferred to B.
- If option A has an identical score to option B, then A and B are indifferent.

The issue of incomparability does not arise in this method, since two utility scores are always comparable, and even transitive. That means that if option A is better option B, and option B is better than option C, then we can assume that option A is better than option C.

Therefore, it was realized that it is probably the utility value of a particular alternative that is actually used by humans for decision making. So, these value-based theories actually proposed the importance of utility value, instead of the expected value in human decision making. Decision makers' preferences are determined using an appropriate utility function.

2.3.3.1. WSM – Weight Sum Model

Churchman and Ackoff (1954)[9] first utilized the WSM method to cope with a portfolio selection problem. The WSM method (or **SAW - SUM ADDITIVE WEIGHTINGH**) is probably the best known and widely used method for multiple attribute decision making (MADM). Because of its simplicity, WSM is the most popular method in MADM problems and the best alternative can be derived by the following equation:

$$A^* = \left\{ u_i(\boldsymbol{x}) \mid \max_i u_i(\boldsymbol{x}) \mid i = 1, 2, \ldots, n \right\},$$

or the gaps of alternatives can be improved to build a new best alternative A* for achieving aspired/desired levels in each criterion. Also:

$$u_i(\boldsymbol{x}) = \sum_{j=1}^{n} w_j r_{ij}(\boldsymbol{x}),$$

where *ui(x)* denotes the utility of the *i*th alternative and *i* = 1,2,…,*n*; *wj* denotes the weights of the *j*th criterion; *rij(x)* is the normalized preferred ratings of the *i*th alternative with respect to the *j*th criterion for all commensurable units; and all criteria are assumed to be independent[10]. There is a well-known variation of this method, where the multiplication is used instead of summation – **Weigh Product Model** (WPM). This method is often called dimensionless analysis due to its mathematical structure that eliminates any units of measure. It can be used in single- and multidimensional MCDM problems. That is, on decision problems where the alternatives are described in terms that use different units of measurement. An advantage of this method is that instead of the actual values, one can also use relative values (through normalization).

2.3.4. MACBETH

MACBETH stands for "Measuring Attractiveness by a Categorical Based Evaluation Technique". This method has many similarities with AHP. Both methods use pairwise comparisons, however MACBETH uses an interval scale ($A - B$) instead of a ratio scale (A/B), adopted by AHP. The calculations processes involved also differ from a method to another. The main distinction between MACBETH and the other MCDA methods is that MACBETH only requires

qualitative judgements about the differences of attractiveness between two elements at a time, in order to generate numerical scores for the options in each criterion and to weight the criteria. MACBETH offers seven semantic categories for the evaluations, as shown in Table 2.5.

Table 2.5 Semantic categories in MACBETH

Semantic Categories	Quantitative scale
no	1
very weak	2
weak	3
moderate	4
strong	5
very strong	6
extreme	7

Using these semantic categories, three types of scores are calculated[6]:

- **Weighting criteria**, to measure the attractiveness of each criterion in relation to the main goal.
- **Score of options**, which represent the attractiveness of an option to one specific criterion.
- **Overall score of options**, where the value scores of the options are subsequently aggregated additively to calculate the overall value scores that reflect their attractiveness taking all the criteria into consideration, generating a ranking of the options with regard to the overall objective.

The problem is structured in a value tree, making a distinction between criteria and non-criteria nodes. Non-criteria nodes are included in the tree with the purpose to help in the evaluation of the criteria, but are directly involved in the decision, since they only act as comments to structure the problem.

Using pairwise comparisons, the relative attractiveness of each criterion is evaluated, and then the options are compared pairwise with regard to each criterion, generating judgement matrices, where differences of attractiveness are expressed. An example is showed in Table 2.6.

Table 2.6 Matrix of judgement

	Criterion 1	Criterion 2	Criterion 3
Criterion 1	no	weak	moderate
Criterion 2		no	weak
Criterion 3			no

From such a matrix of judgements, weights and scores of options are calculated, using linear programming.

When filing a judgement matrix, there's the possibility of introducing incompatible judgements. Unlike AHP, in MACBEH the calculations can only proceed if the matrix is sufficiently *consistent*, otherwise some of the judgements need to be revised. So, the incompatibility check is a fundamental step in this method. There are two types of incompatibility[6]:

- **Incoherence inconsistency**: conflict between a comparative judgement (that is given between two action on a semantic category, for example: A is moderately more attractive than B) and a semantic judgement (comparison between two comparative judgements, for example (the difference in attractiveness between A and B is bigger than between A and B).
- **Semantic inconsistency:** tested by a linear program, where basically "two paths" between two points (representing the preference strength), should have the same "length".

Each alternatives' scores based on the criteria are calculated and then weighted with the criteria weight to find the overall scores. Overall scores are then used to rank the alternatives from the most attractive to the less attractive.

Similarly, to other methods, a sensitivity analysis can be performed after all the calculations, as well as a robustness analysis which is important when facing an uncertain problem with imprecise information.

2.3.5. PROMETHEE

PROMETHEE (Preference Ranking Organization METHod for Enriched Evaluation) method will provide the decision maker with a ranking of actions (choices or alternatives) based on preference degrees. It follows three main steps:

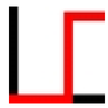
1. The computation of preference degrees for every ordered pair of actions on each criterion – unicriterion preference degrees

A preference degree is a score between 0 and 1 that express how an action is preferred over another action, considering the decision maker perspective. If there is no preference between two alternatives with respect to a certain criterion, then the value is 0, while the value of 1 represents a total or strong preference for one of the action on the considered criterion. A value between 0 and 1 is a weak preference, i.e., there is some preference but not a total preference. These pairwise comparisons are made using preference functions. The most common ones are shown below on Figures. In order to specify a preference function, two parameters are required: preference (*p*) and indifference (*q*) thresholds. In the Gaussian case only the inflexion point (*s*) is needed, instead of the two thresholds.

Type I: Usual preference function

Usual preference function is the simplest one. The larger the value, the better. There is no need to include thresholds here (q=p=0). It's usually used when considering qualitative criteria, where a one-level difference is already important ("good" is preferred to "average").

Type II: U-shape preference function

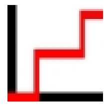


The U-shape introduces the indifference threshold. If the difference between the evaluations on a criterion is smaller than the indifference threshold, then no difference can be perceived by the decision maker between the two actions.

Type III: V-shape preference function

The V-shape has an indifference of 0 and a preference value above 0. It is well suited for quantitative criteria where even small deviations should be considered. If the difference between the evaluations on a criterion is bigger than the preference, then the preference is strong.

Type IV: Level preference function



The Level preference function is better suited to qualitative criteria when the decision maker wants to modulate the preference degree according to the deviation between evaluation levels.

Type V: Linear preference function

Best choice for quantitative criteria when both thresholds are wished.

Type VI: Gaussian preference function

It has a smoother shape but it is more difficult to set up because it relies to a single *s* (inflexion point) threshold that is between the indifference and preference thresholds and has a less obvious interpretation. It is seldom used.

2. The computation of unicriterion flows

After all comparisons are done, the criterion preference degrees are summarized in the so-called unicriterion leaving (positive) flows, entering (negative) flows and the net flows. The leaving flow represents how an action is preferred to all other actions on that particular criterion. The bigger this flow is, the more preferred it is compared to other actions. On the other hand, the entering flow measure how the other actions are preferred to a certain action. Both of these flows are obtained by taking the average of all the preferences of an action compared to others or all the preference degrees of the actions compared to that particular action, respectively (excluding the preference degree compared with itself). Their values lie between 0 and 1. Finally, by taking the leaving and entering flows into account, we can obtain the net flows by subtracting the entering flows from the leaving flow. This score represents the balance between the global strength and the global weakness of an action, so it as to be maximized. Its value lies between -1 and 1.

3. The computation of global flows

The previous steps considered only one criterion. To take into account all the criteria at the same time, it is necessary to provide the relative importance of each criterion. This means that the decision maker needs to specify a weight to each criterion that will allow him or her to aggregate all the unicriterion leaving, entering and net flows into global leaving flows, global entering flows and global net flows.

Similarly, to the unicriterion leaving flow, the global leaving flow represents how an action is globally preferred to all other actions, but this time considering all criteria instead of just one. Analogously, the global entering flow indicates how an action is globally preferred by other actions. The global net flows result from an identical method as the unicriterion net flow: subtracting the global entering flow from the global leaving flow. It takes into account both point of view: being preferred over or being preferred by.

After calculating all the global flows, we obtain two rankings:

PROMETHEE I ranking:

The alternatives are ranked based on both leaving and entering flows. These rankings are then used to calculate a partial preorder, where certain alternatives may remain incomparable – partial ranking. Four possible scenarios can arise:

a) An action is preferred (has a better rank) to another if it has a higher global leaving flow and a lower global entering flow.

b) An action has a worse rank than another if it has a lower global leaving flow and a higher global entering flow.

c) Two actions are indifferent if they have identical global leaving and entering flows.

d) Two actions are said to be incomparable if one has a higher global leaving flow and a higher global entering flow or a lower global leaving flow and a lower global entering flow.

PROMETHEE II ranking:

Here, the global net flow is used, leading to a complete ranking of the actions, where the incomparable status no longer exists. The actions are ordered from best to worst.

The PROMETHEE method can also be submitted to a sensitivity analysis.

2.3.6. ELECTRE

ELECTRE stand for *ELimination Et Choix Tradusation la REalité* (elimination and choice expressing reality). The ELECTRE methods also belong to the outranking methods and they constitute one of the main branches of this family. Over the years several ELECTRE methods were developed in order to tackle new decision problems, so they can be subdivided according to the type of problem that they are attempting to solve. Table 3 summarizes the different ELECTRE methods.

Table 2.7 Overview of ELECTRE

Decision Problem	Method
Choice problem	ELECTRE I ELECTRE Iv ELECTRE Is
Ranking problem	ELECTRE II ELECTRE III ELECTRE IV
Sorting problem	ELECTRE-Tri-B ELECTRE-Tri-C
Elicitation problem	Elicitation of the weights in ELECTRE Elicitation for ELECTRE-Tri: • IRIS method • other elicitation methods

The main characteristic and advantage of these methods is that they avoid compensation between criteria and any normalization process, which distorts the original data. They involve a higher degree of complexity, that can be a drawback, because of the requirement of difficult technical parameters, becoming harder to fully understand and even to handle.

The focus will rely on the ELECTRE III ranking method. ELECTRE III makes use of outranking relations, where ***A*** outranks ***B*** (denoted by ***A*** *S* ***B***) expresses the fact that there are enough arguments to decide whether ***A*** is at least as good as **B** and there is no sufficient argument to refute this. This method also considers the preference and indifference thresholds, such as PROMETHEE. However, a new threshold is introduced: the veto threshold. Veto thresholds express the power attributed to a given criterion to be against the assertion "***A*** outranks ***B***", when the difference of the evaluation between ***B*** and ***A*** is greater than this threshold.

The strength of the assertion ***A*** outranks ***B*** can be measured using the outranking degree *S* (***A***, ***B***). This is a score that lies between the values of 0 and 1, and the assertion will have more strength, the closer this value is to 1. The outranking degree is divided in two perspectives: **concordance**, relative to the preference and indifference thresholds; and **discordance**, that considers the veto threshold (v).

Concordance

A partial concordance degree *c* (***A***, ***B***) measures the assertion "***A*** outranks ***B***" or "***A*** is at least as good as ***B***" on a specific criterion. For example, if we consider the purchase of a smartphone, the storage is an important criterion to be accounted. Assuming that ***A*** is a smartphone with 32 GB and ***B*** a smartphone with 16 GB, we can easily conclude that the ***A*** is at as good as ***B***, since storage has to be maximized. The assertion is strong because smartphone ***A*** storage is bigger than smartphone ***B*** storage, and as a result as good. The partial concordance will therefore be equal to 1. In opposition, let's consider the assertion "***B*** outranks ***A***". This can be true or false, depending on the decision maker viewpoint: 16 GB of difference can be considered negligible for a person, while for another individual it can be seen as a relevant difference. Therefore, the preference and indifference thresholds need to be specified in order to measure the difference of performance.

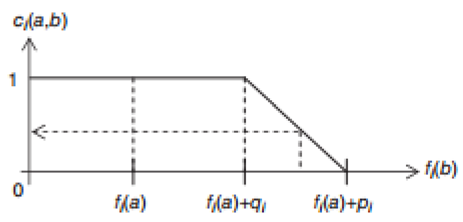


Figure 2.6 Partial concordance

Figure 4 shows how the partial concordance with regard to a certain criterion varies. Considering the assertion "***A*** outranks ***B***", three scenarios can emerge (based on Figure 4):

a) If the performance of ***B*** is smaller than the performance ***A*** augmented with the indifference threshold (*q*), ***A*** and ***B*** are indifferent. The concordance degree is 1.

b) If the performance of ***B*** is higher than the performance of ***A*** augmented with the preference threshold (*p*), there is a strict preference of ***B*** over ***A***. The concordance degree is 0.

c) If the performance of ***B*** is between the performance ***A*** augmented with the indifference threshold (*q*) and the performance of ***A*** augmented with the preference threshold (*p*), then ***B*** is weakly preferred to ***A***. The concordance degree is between 0 and 1.

The global concordance degree *C* (***A***, ***B***) can be obtained by aggregating all the partial concordance indices of the different criteria taking in consideration their corresponding criteria weights. The global concordance measures how concordant the assertion "***A*** is at least as good as ***B***" with respect to all criteria.

Discordance

Contrary to concordance, we have the partial discordance degree *d* (***A***, ***B***) that measures the decision maker's discordance with the assertion "***A*** is at least as good as ***B***" on a certain criterion. When this degree reaches his maximum value of 1, it means that the decision maker strongly disagrees on the assertion, while considering a certain criterion, and it reflects that the criterion sets his veto. This happens when the difference between the performance of ***B*** and ***A***, is higher than the veto threshold. If the discordance degree is 0, there is no reason to refute the assertion. Figure 5 shows how the partial discordance degree can vary.

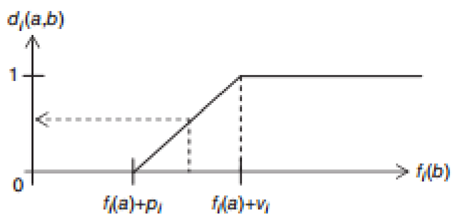


Figure 2.7 Partial discordance

In the same as way the partial concordance, there are three possible scenarios:

a) If the performance of ***B*** is higher than the performance of ***A*** augmented with the veto threshold (*v*), we have total discordance. The discordance degree is 1.

b) If the performance of ***B*** is smaller than or equal to performance of ***A*** augmented with the preference threshold (*p*) there is no discordance. The discordance degree is 0.

c) If the performance of ***B*** is between the performance ***A*** augmented with the preference threshold (*p*) and the performance of ***A*** augmented with the preference threshold (*v*), then ***B*** is slightly preferred to ***A***. The discordance degree is between 0 and 1.

The global discordance degree *D* (***A***, ***B***) can be obtained by aggregating all the partial discordance indices of the different criteria taking in consideration their corresponding criteria weights.

The outranking degree summarizes both global concordance and discordance degrees into one measure of the assertion "***A*** outranks ***B***" using a complex formula that includes additional parameters.

The final step of the process is the **distillation**. It consists on exploiting the pairwise comparison degrees, by creating an ascending and descending distillation, each one leading to a complete pre-order. Each pre-order considers the outranking and outranked behavior of each alternative regarding all other alternatives. Then a final ranking is generated (a partial ranking), resulting from the intersection of the two previous pre-orders.

2.3.7. TOPSIS

TOPSIS stands for Technique for Order Preferences by Similarity to an Ideal Solution and was proposed by Hwang and Yoon (1981). The main idea of this method came from the concept of the compromise solution to choose the best alternative nearest to the positive ideal solution (optimal solution) and farthest from the negative ideal solution (inferior solution). Then, choose the best one of sorting, which will be the best alternative. TOPSIS was proposed to determine the best alternative based on the concepts of the compromise solution. The compromise solution can be regarded as choosing the solution with the shortest Euclidean distance from the ideal solution and the farthest Euclidean distance from the negative ideal solution[10].

The TOPSIS method requires only a minimal number of inputs from the user and its output is easy to understand. The only subjective parameters are the weights associated with the criteria. For example, in Figure 2.8, where both criteria are to be maximized, alternative A is closer to the ideal solution than B and further from the anti-ideal solution if the criteria weights are equivalent. As a result, TOPSIS presents alternative A as a better solution than alternative B[6].

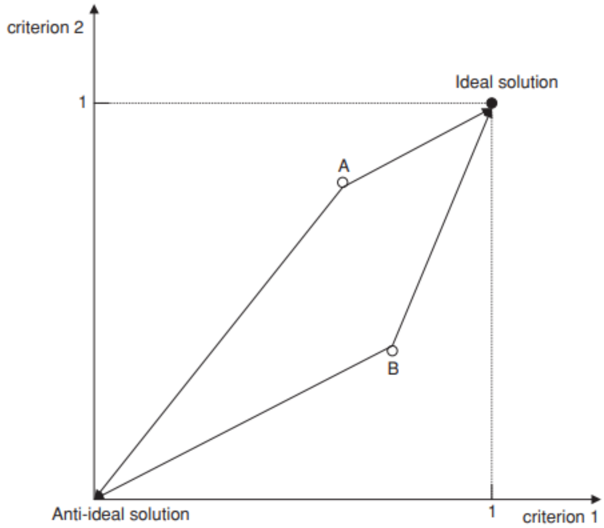


Figure 2.8 Distances to ideal and anti-ideal solution. *Adapted from Ishizaka & Nemery, 2013.*

The TOPSIS method is based on five computation steps. The first step is the gathering of the performances of the alternatives on the different criteria. These performances need to be normalized in the second step. The normalized scores are then weighted and the distances to an ideal and anti-ideal point are calculated. Finally, the closeness is given by the ratio of these distances.

2.3.8. VIKOR

The *VlseKriterijumska Optimizacija I Kompromisno Resenje* (VIKOR) method was developed for multicriteria optimization of complex systems. It determines the compromise ranking list, the compromise solution, and the weight stability intervals for preference stability of the compromise solution obtained with the initial (given) weights. This method focuses on ranking and selecting from a set of alternatives in the presence of conflicting criteria. It introduces the multicriteria ranking index based on the particular measure of "closeness" to the "ideal" solution[11].

Assuming that each alternative is evaluated according to each criterion function, the compromise ranking could be performed by comparing the measure of closeness to the ideal alternative. The compromise solution *Fc* is a feasible solution that is the "closest" to the ideal *F** and compromise means an agreement established by mutual concessions[10].

VIKOR is a helpful tool in multicriteria decision making, particularly in a situation where the decision maker is not able, or does not know, to express his/her preference at the beginning of system design. The obtained compromise solution could be accepted by the decision makers because it provides a maximum "group utility" of the "majority" and a minimum of the individual regret (represented by *minR*) of the "opponent." The compromise solutions could be the basis for negotiations, involving the decision makers' preference by criteria weights[10].

Unlike most of the MCDM methods, where the alternative are given by a score and the best alternative is the one with the higher score, in this case the final output are "distances". So, when using VIKOR the best alternative is the one with the lower value, because that value represents the distance to the compromise solution, therefore is the closest to the ideal point.

2.3.9. Goal Programming

Goal programming is an extension of linear programming to handle multiple conflicting objectives. The main idea of goal programming is that there is an ideal goal to be achieved while also satisfying hard constraints. This goal is composed of several objectives that may be conflicting. The main difficulty is the modelling of the problem: to find the goal and the soft and hard constraints[6].

This method approach establishes a specific numerical goal for each of the criteria and then attempts to achieve each goal sequentially up to a satisfactory level rather than an optimal level.

If constraints are used to construct the goals, then the goals are to minimize the violation of the constraints. The goals are met when the constraints are satisfied.

Unwanted deviations from the set of target values are then minimized in an achievement function. This can be a vector or a weighted sum dependent on the goal programming variant used.

Goal programming is used to perform three types of analysis:

- Determine the required resources to achieve a desired set of objectives.
- Determine the degree of attainment of the goals with the available resources.
- Providing the best satisfying solution under a varying amount of resources and priorities of the goals

2.4. Weighting Methods

In this dissertation, only a few of the mentioned methods below were considered. In Chapter 4, more detailed information about the selected methods is presented.

Criteria weighting is a key element of multi-criteria decision analysis, that is becoming extensively used in several sectors. Determining the weights it's a necessity that arises most of the times in MCDA problems and taken into account that weights can significantly influence the final outcome of the process, it becomes extremely important to pay particular attention in this step. In the past years, several researchers have up come with different techniques to assign weights to criteria in a MCDA process. Those techniques can be sorted in three main groups (Table 2.8):

- Subjective: based on expert opinion, and in order to get the subjective judgments, analyst normally presents the decision makers a set of questions in the process[12].
- Objective: derive their information from each criterion by adopting a mathematical function to determine the weights without the decision-maker's input[12].
- Integrated: combination of subjective and objective.

Table 2.8 Weighting methods *(Odu, 2019)*

	Weighting methods	
Subjective weighting methods	**Objective weighting methods**	**Integrated weighting methods**
Point allocation	Entropy method	Multiplication synthesis
Direct rating	Criteria Importance Through Inter-criteria Correlation (CRITIC)	Additive synthesis
Ranking method	Mean weight	Optimal weighting based on sum of squares
Pairwise comparison (AHP)	Standard deviation	Optimal weighting based on relational coefficient of graduation
Ratio method	Statistical variance procedure	
Swing method	Ideal point method	
Delphi method		
Nominal group technique		
Simple Multi-attribute Ranking Technique (SMART)		

2.5. Comparison and selection of methods

As it could be seen, there are several techniques at our disposal, which means that there is a need to select one (or at least a few in a more preliminary phase) to apply. When selecting an MCDA or weighting method there aren't a set of rules that define which ones is the best. Actually there are no right or wrong answers probably. What can be said is that there are "a more accurate" or a "less correct" method to use considering the situation and the circumstances that are being faced. It is possible to make an assessment based on the information that we have available and the type of results we want.

Evaluating the type of decision problem is a good start. As mentioned before, there are four types of problems: sorting, choice, ranking and description. The outranking methods are usually popular when talking about sorting (and even description) problems, since they have the ability to provide partial or complete rankings, being the former more relevant in this scenario, because they make it possible to order all the alternatives, even the ones that are incomparable. If A2 and A3 are incomparable we can't say which one is best. However we can state that they are both better than A4 and worse than A1, and that represent a great feature in these methods. Another great feature is the possibility to add more information to the MCDA model by using the preference and indifference thresholds, and the veto threshold too in the case of ELECTRE. These thresholds allow for a better modelling of the problem, shaping the importance of the criteria in a way that the other method can't. On the other hand, they are not easy to establish and that process must be rigorous, because it represents another subjective element in the process, that will highly impact the outcome of the results. It's not advisable to apply the outranking techniques if these criteria are defined properly or if they have a significant amount of uncertainty associated. Ranking problems are the most common, that's why the full aggregation approach is one that reveals a bigger presence in the MCDA studies. These methods provide the a final score for every alternative regarding the criteria and the better the score, the better the ranking, the better is the solution. They are often simpler processes that do not require that much information and are easier to apply. Although the ideal and anti-ideal options techniques, such as TOPSIS or VIKOR can fit in this problem, they can also be used in the choice problem, since that's exactly their objective: finding the solution that is the closest to perfect scenario is what their aim. While in the ranking problems we have several available alternatives and want to understand how each one performs considering the criteria that are being considered, in the choice problem there is a pre-defined goal to achieve and our objective is to find the option that is closer to that goal. These two types of problems may seem very similar at first, but the approach in each one is different, and that's the main reason why is so important to assess what method or methods to use, so we'll be able to obtain the information that we desire.

Understanding the data that is available for a certain problem is something to consider too. The indicators that are going to be used in the model can assume three forms: quantitative, qualitative or mixed. While it's advisable to work with the same type of data, is not wrong to have more than one type, as long as the due adjustments are made. This is where the normalization step enters into scene. As showed before there are different normalizations processes and they should be adequate to the data and situation. Then, the amount of alternatives and criteria is another factor to take into account. There are four possible scenarios, that described in Table 2.9.

Table 2.9 Scenarios related with number of criteria and alternatives

Number of Evaluation Elements	Typology of Indicators	Expected Solution	Technical support of a Decision Aid Specialist	Stakeholders to Be Included in the Decision Process	Tool
Limited number of criteria and sub-criteria and a small number of alternatives	- Quantitative; - Qualitative; - Mixed	Definition of n alternatives valid in relation to objectives	- Yes; - No	- Participatory process not activated; - Participatory process activated with a limited and specialized number of stakeholder; - Participatory process activated with a significant number of stakeholder preferably organized in categories	ELECTRE
Limited number of criteria and sub-criteria and a large number of alternatives		A better overall alternative definition for the purpose; The ideal alternative definition closest to the lens			MAUT
Large number of criteria and sub-criteria and a small number of alternatives					AHP; ANP
Large number of criteria and sub-criteria and a large number of alternatives					MACBETH; PROMETHEE; TOPSIS

Some MCDA methods have their own way to assign weights to the criteria, while other don't. The weight of criteria are one element that usually add subjectivity to the model. That is not a bad thing necessarily, since it allows to attribute relative importance to different criterions. Very often we are faced with decisions where some factors are clearly more important than others, but by how much? That considerations is something that needs to made carefully, otherwise one criterion can have too much weight making all other criterions almost irrelevant or, by opposition, one criterion as a weight so low that regardless its score it won't matter. The elements that add subjectivity to the problem are usually defined by stakeholders or field experts, and most of the times they are established in group. But the option of following a more objective path is also a possibility, by using the objective techniques. However subjectivity is something inevitable in an MCDA model; we can control its presence but not avoid it. Even if we opt to take the objective way that's already a choice that we made.

The implementation procedure is another thing that guide us during the selection of a method. There are different types of implementation procedure commonly used:

- Pairwise comparisons on a ratio scale:

  Arguably one of the most used method, that constitutes the base of AHP. Includes evaluation matrices, that contain the comparison of the elements of the problem. It is structured based on a hierarchical system of criteria, sub-criteria and alternatives and it is performed by simultaneously comparing two element at a time regarding the superior element on the hierarchy and on a basis of rational numerical scale.

- Pairwise comparisons on a ratio scale with interdependences:

Similar to the previous one but more complex. ANP is the technique that uses this implementation. Consists in the construction of evaluative matrices forming a bigger one called Supermatrix. In this matrix, the comparisons between elements are organized in clusters of criteria, sub-criteria and alternatives and are performed simultaneously by comparing two element at a time considering the interdependences between them. These dependencies can be inner dependencies in the criteria cluster, inner dependencies in the alternative cluster or outer dependencies. The Supermatrix is completed considered the influence of each node on the other and expressed in a rational scale. When there no interdependencies between two elements, a 0 is insert in the Supermatrix in the correspondent position.

- Utility function:

Commonly possible when is possible to establish the function. MAUT (or MAVT) is the method associated with these technique. It consist in the expression of the measure of desirability or preference of each alternative with respect to the rest. Different criteria are considered in the function. For each criterion, it is calculated a value named marginal utility, which represent the partial contributing that that criterion brings to the overall utility evaluation. Then the Global Utility Score is usually calculated by the additive model or with a weight some.

- Pairwise comparison on an interval scale:

This technique utilizes matrices of judgements, that are based on a interval scale instead of a ratio. The comparison between alternatives and criteria is implemented by pairwise comparisons based on a semantic qualitative scale. Values are generally included in a the matrix of judgments where the relative attractiveness of the criteria and alternatives is expressed by the consideration of the weight attributed to each criterion.

- Threshold - Preference, indifference and veto:

A pairwise preference degree is made comparing the performance of various alternatives. To find the preference level, the assessment should take into account the preference and indifference thresholds. On the basis of these thresholds are created the positive, negative and unicriterion net and global flows that consider the weights assigned to each criterion. If an action performs negatively regarding to a specific criterion, a veto threshold may be included in order to exclude that option in the final ranking. PROMETHEE and ELECTRE (in the case of veto) are the methods that use this approach.

- Ideal option and anti-ideal option:

VIKOR and TOPSIS are examples of methods that use this kind of calculations. The idea here is the expression for each alternative, of the shortest distance to the ideal and the longest distance from the anti-ideal solution, considering the performances of the alternatives regarding each criterion and its respective weight.

Table 2.10 sumarizes the relations between the different MCDA methods.

Table 2.10 Required inputs for MCDA methods. *Adapted from Ishizaka & Nemery, 2013*

Inputs	Effort input	MCDA method	Output
utility function	Very HIGH	**MAUT**	Complete ranking with scores
pairwise comparisons on a ratio scale and interdependencies	↑	**ANP**	Complete ranking with scores
pairwise comparisons on an interval scale		**MACBETH**	Complete ranking with scores
pairwise comparisons on a ratio scale		**AHP**	Complete ranking with scores
indifference, preference and veto thresholds		**ELECTRE**	Partial and complete ranking (pairwise outranking degrees)
indifference and preference thresholds	↓	**PROMETHEE**	Partial and complete ranking (pairwise preference degrees and scores)
ideal option and constraints	Very LOW	**Goal programming**	Feasible solution with deviation score
ideal and anti-ideal option		**TOPSIS**	Complete ranking with closeness score

3. Post-mining indicators

The mining activity is one of the most important activities for the supplying of Raw Materials for many industries. It is something inevitable and indispensable in the modern society. However, if proper measures are not taken, mining may result in some adverse impacts at various levels, such as impacts on the natural environment and surrounding landscapes or changes in the people's lifestyles. Several examples in the entire world can be taken where, after the closure of the mines, large areas remain contaminated and unexploited. In the process of mine closure, the identification of an adequate potential land use for the post-mining periods that promotes its rehabilitation will help to improve social acceptance of mining activity. In this process, Multicriteria Decisional Analysis (MCDA) may be applied to support decision makers and stakeholders taking into consideration several distinct types of criteria such as Environment, Economic, Geoethical, Potential Regional Development conditions, among others[13]. In order to apply a MCDA methodology is necessary to identify the relevant criteria to be considered so that different available alternatives can be evaluated and compared between themselves. This process will allow the users to define a ranking of distinct solutions and to determine "the best possible alternative". The goal is the selection of an optimal post-mining land use after the closure of the mining area. However, there are several factors that need to be considered. In this regard, we identified five main groups of criteria: economic, environmental, geoethical, technical issues and potential for regional development. Each group of criteria is then divided into sub-criteria. Each sub-criterion can be classified qualitatively and/or quantitatively and are not conditional to the analysis, that is, according with the study cases may or may not be considered and can be also adapted according to type of available information.

3.1. Economy of the post-mining process

Post-mining revitalisation projects can have high budgets or lower budgets depending on several aspects, for instance, the need to decontaminate the water and land, the desired final solution, the possibility for funding and the time vs urgency for project development. For this, when thinking on a suitable project for the rehabilitation of a mining site, the economic aspects are of major importance, because, on the one hand, they are what funds the project and make it possible but, on the other hand, imposes constraints to the idealised and desired solution.

In order to have a realistic overview of the economic impact to the rehabilitation project for the post-mining land use, there is the need to assess aspects such as the cost of the revitalisation works, the time available and needed to develop the project, the balance between monitoring costs and value added after revitalisation, and the funding available for the project.

The main objective is to make a return possible on investment, so that potential funders or active participants gain interest in the project[14]. The optimal point at which the return is maximised is not easy to calculate, but it's what we should always aim at. In this case, the Optimal Point represents the best relation between financial input in the project and increasing benefit that results from regeneration of the site. The objectives of the revitalisation of the land and local communities are important, but have to be well thought. To see an abandoned mine as a risk or problems is missing an opportunity where income can be generated, however limitless investment to the project is not a responsible attitude regarding the available funds, because the scenario where the costs outweigh additional benefits it's also not ideal.

In this analysis the economic criterion contemplates four sub-criteria (see Table 3.11).

The sub-criterion costs associated with rehabilitation, monitoring and control, remediation, reclamation and recovery process regards to the effective costs of the field work needed to develop the mine's rehabilitation project, costs associated with monitoring and control of the field works and costs related to land expropriation and purchase.

The time sub-criterion regards with time management. In this sub-criterion the time needed for the field works will be evaluated, their urgency and also the relationship between the project's execution time and the time when its impacts will be visible (whether positive or negative), because a project that takes longer to be concluded will imply higher spending, but on the other hand, if the processes are somehow rushed, it could lead to safety concerns or low quality results.

The Post-mining economic balance is considered as an economic sub-criterion and includes the assessment of the selected post-mining solution's economic potential and the costs associated with monitoring and maintenance of the site after rehabilitation.

Finally, it must be considered the mine's rehabilitation funding/investment that can be provided by different sources (mine companies, government entities, SMEs, private investors, other), and may reflect on budget available for the rehabilitation project. The type of funding can also vary and include options like guarantee, loans and grants, that should be considered according to each alternative, because a more commercial alternative may be favourable to loans, than a non-commercially alternative.

Table 3.11 Economic Criteria

ECONOMIC CRITERIA							
SUB-CRITERIA		**ATRIBUTES**		**DESCRIPTION**	**EVALUATION**		**UNITS/SCALE**
					Qualita-tive	**Quantita-tive**	***Suggestion***
1.1	Costs associated with rehabilitation, monitoring and control, remediation, reclamation and recovery process	**1.1.1**	Operating costs associated to field works	Machinery and/or Technology maintenance/upgrades, technical procedures costs, labor/salaries, resources/materials in the requalification/rehabilitaiton stage		X	Currency
		1.1.2	Maintnence and monitoring costs of the intervention	Costs associated to the maintenance and monitoring of the work during the mining rehabilitation/requalification work		X	
		1.1.3	Expropriation or purchase of land	The costs related to expropriation or land purchase processes		X	

1.2	**Time**	**1.2.1**	Characterization of impacts and project development of alternatives solutions	This will be very important for time management, because the kind of solution that will be applied needs to take into account the financial possibilities and the impacts it might have. This means that different solutions require different times	X		Classification: 1-weak, 2-not satisfatory, 3-good, 4-great, 5-excellent
		1.2.2	Time available/urgency	Understand if the realization and conclusion of the intervention is urgent (if the processes are rushed, the probabilities of acidents are higher, however more time implies more money spent)		X	Months
		1.2.3	Time needed for field work execution	The time the requalification/rehabilitaiton will take to be concluded		X	
1.3	**Post-mining economic balance**	**1.3.1**	Economic potential of the Post-mining land use (PMLU)	Analyse the potential for economic growth regarding the PMLU option	X		Low, medium, high, very high
		1.3.2	Monitor and maintenance costs	Costs associated with the monitoring and control of the site after the requalification/rehabilitation operations, including workers salary		X	Currency
1.4	**Mine closure funding/Investment**	**1.4.1**	Source	The source and/or amount of funding for the mine closure and reclamation project.	X		Mine company, national government, regional government, other investors, mix.
		1.4.2	Type	The way and/or amount of fundind that will be made	x	x	1-5 scale

3.2. Environmental

The mining activity requires long periods of occupation of land that last for decades. The closure of a mine usually leads to the abandon of the area without considering the future of that zone. The abandon of mining area must be done in a pondered and responsible way, without, so that another use can be attributed to that area, and assuring there are no impacts in the surrounding environment. In the cases where there is no revitalisation process, the abandoned sites can reach to a degradation level that won't allow its utilization for another kind of activity[15].

In order to determine the local situation before implementing a project it is essential to verify distinct environmental criteria, so to develop an up-to-date physical environmental characterisation. Moreover, this information will be also valuable for the future, to evaluate the impacts generated during and after the interventional stage. The identification of suitable post-mining land use is highly dependent on the environmental conditions of the site. For this reason, the collected data must be adequate to the scale of the project and capable of representing temporal and spatial trends of the factors that are being considered. Ecosystems can vary at spatial and temporal level, being sometimes highly dynamic with variations rates that can easily change. For a correct and complete evaluation, some of the information needs to be gathered on the field and other is already available. When collecting data, a suitable collecting method must be used to ensure scientific representativeness of the results and the use of applied legal framework must be considered whenever possible.

The impacts in the environment that can arise from the mining activity are directly related to characteristics of the place and to the processes that are being performed in that place. These impacts can cause different types of effects, such as: the total or partial loss of a resource (soil, species, landscape), the increase of the probability of occurrence of some undesired phenomes, like erosion for example, the contamination of superficial or underground water, or changes in the drainage networks[15].

Four sub-criteria were identified in the environmental criterion and described below (see Table 3.12).

- Atmospheric: which has the objective to characterise the regional climate situation, air quality, the noise and vibration issues, including, when possible the applied legal frameworks. The most common issue in this group are the emission of gases and dust. The gases are mainly prevenient from the combustion of the machinery and vehicles. The dust is essentially caused by works of drilling, cargo and transportation. Other type of problem is related to the noise and vibrations. The explosives are the main source, but the machines also represent part of this problem.

- Aquatic: in which is intended to characterise the surface and groundwater resources, as well as their quality. The contamination of waters is one of the biggest concerns in the mining activity. It can occur chemical contamination due to chemical alteration of the minerals or physical contamination when there is drag of fine particles. The chemical contamination can result in acid waters, that can lead to the dissolution of some heavy elements. Similarly, the contact between specific substances and neutral waters from the hydrographic network can create a precipitate that will affect the growth of aquatic plants. On the other hand, the physical contamination heavily affects the fish species in the area.
- Terrestrial: that includes geology and geomorphology characterisation; the physical, chemical and distribution characterisation of tailings, waste dumps, heap leaching materials (and others); soil and land occupation identification; and the analysis of landscape indicators in the mine complex and its surroundings. The loss of natural soil, changes in the morphology and risks associated with the stabilizing factors of the land are some impacts to be aware. The chemical contamination also plays a big part in this group, since heavy metals or acidity can cause problems in the vegetation growth, which leads to an increase in erosion. This group also includes the impacts in the landscape.
- Biological: that englobes the characterisation of fauna and flora, the relation with protected areas and the agricultural land quality analysis. By eliminating part of the vegetation, some habitats are being destroyed, and as a consequence some species will be very affected. It's easy to understand how the activities of a mine can drastically disrupt the life of the species of the area. It can reach alarming cases, where by changing the fluvial dynamic, some populations of fish species are destroyed.

There is a lower level of sub-criterion not described in this document, where is specified the parameters to be considered in each sub-criterion, that are presented in Table 3.12. [2]

[2] *Note: Archaeological aspects that are usually considered in EIA, in this case, are included in Geoethical criteria.*

Table 3.12 Environmental Criteria

ENVIRONMENTAL CRITERIA							
SUB-CRITERIA		**ATRIBUTES**		**DESCRIPTION**	**EVALUATION**		**UNITS/SCALE**
					Qualitative	**Quantitative**	***Suggestion***
2.1	**Atmospheric**	**2.1.1**	Climate	Regional climate, temperature, precipitation, relative air moisture, wind regime, fog and cloudiness, rime ice, hail, snow and thunderstorms, hydric equilibrium, climate change impact (eg.: CO_2 emissions)	X		Metereological data
		2.1.2	Air quality	Legal framework, particles in suspension concentration (eg. PM10), CO_2 and PCDD/F concentration (eg.: CO_2, O_3, CO, SO_2, NO_2), radon exhalation, radiological parameters (individual and site domestry)		X	
		2.1.3	Noise and Vibration	Legal framework, potential receivers, existing noise sources, baseline characterisation. Vibration *LAeq* in fast and impulsive mode. Frequency classes from octave bands.	X	X	
2.2	**Aquatic**	**2.2.1**	Surface water resources	Hydrographical network and hydrologic basin, surface run-off and local flood flow, hydro-chemical and radiological characterization (local and regional background), hydro-chemical and radiological characterization of the sediments (in suspension and on the riverbed, local and regional background), legal framework.	X	X	Parameters values 1-5 scale
		2.2.2	Groundwater resources	Local groundwater levels and main flow directions, public exploitations (and its protection perimeters), hydro-chemical and radiological characterization (local and regional background, Infiltration potential, legal framework.	X		1-5 scale
		2.2.3	Water quality	Identification of the applicable local and regional legal framework (and correspondent directives), tailoring to local situation, legal framework.	X		1-5 scale

ENVIRONMENTAL CRITERIA							
SUB-CRITERIA		**ATRIBUTES**		**DESCRIPTION**	**EVALUATION**		**UNITS/SCALE**
					Qualitative	**Quantitative**	***Suggestion***
2.3	**Terrestrial**	**2.3.1**	Geology and geomorphology	Geomorphogical setting, local and regional geological setting, local geological setting and neotectonics and seismic risk.	X		1-5 scale
		2.3.2	Tailings, waste dumps, heap leaching materials (and others)	Waste cartography and recognition; mineralogical, radiological, particle size and geochemical parameters; physical deposit stability; and evaluation of the potential of leaching / reactivity and its equilibrium condition with the system	X	X	1-5 scale Parameters values
		2.3.3	Soil and land ocupation	Soil type and land use classification (erosion, porosity, permeability, conductivity/resistivity, petrologic type of bedrock Unified Soil Classification System). Soil geochemical and radiological characterization (local and regional background): pH, salinity, exchangeable cations, soil depths, pant available water-holding capacity, soil nutrients, organic carbon profiles, annual water balances and erodibility.	X	X	CORINE Land Cover and other.
		2.3.4	Landscape	Regional setting, landscape units, visual accessibility, landscape quality, visual absorption capacity, landscape susceptibility, visibility from sensitive receptors.	X		Landascape quality, visual impact, emission of dust and detrital material
2.4	**Biological**	**2.4.1**	Flora and Fauna	Biogeographical setting (species, functional groups, populations, canopy and contact cover, and rooting depths, sensive or endangered species), species (biodiversity), habitats, potential vegetation, present vegetation.	X		Evaluate disturbance or improvements on ecossystem, environment and habitats
		2.4.2	Protected areas	The type of protected areas and their importance present in the mine complex or in the surroundings.	X		UNESCO, Natura 2000 EU directives, local directives
		2.4.3	Agricultural land quality	Agricultural soil classification	X		Existing classifications

3.3. Geoethical

A set of specific criteria related with “Geoethics” were defined and are proposed to be considered in MCDA processes. The consideration of these new criteria, “Geoethics”, is easily justified once it is an emerging area concerned about the necessity of considering appropriate protocols, developing of good practice codes which integrates scientific issues regarding the abiotic world[16]. Geoethics is an emerging field within the geosciences and, more generally, within science itself[17]. Geoethics highlights the importance of geoscientists and their work in the current civilization, which have social, cultural and economic repercussions and can improve the relationships between the scientific community and the decision makers, mass media and general public, showing the unadulterated truth of scientific research and its results[18]. It strives to create solid guidelines that provide socio-economic solutions that respect the environment, and to inform geoscientists, by giving them a solid background on cultural, ethical and social beliefs[18]. One of the main focus of Geoethics is related with pressing environmental subjects, namely, those that ensure an adequate and sustainable natural resource usage, promoting suitable management of natural risks, and diffusing scientific knowledge and geoeducation, targeted especially at youngsters[18].

Geoethics is a relatively new field of ethics related with interaction of geoscientists with the society and Earth itself. Consists on the reflection and research on the values that serve on the basis of appropriate behaviour and correct practices of human activities within the Geosphere[19]. Geoethics is the mid-point between Geosciences, Philosophy and Sociology, always considering the Economy aspect. The foundations of Geoethics can be based on two famous quotes of Gandhi: “God has provided enough resources for everyone’s need but not everyone’s greed” and “Before starting a development project, first think about the effects which the project would have on poorest of poor people in the society”[20]. In the present days, there is the need to attempt an association between the world geological and philosophical communities with the objective to research and elaborate a set of moral norms of conduct, to be applied in any social or professional activity, including those who are engaged in research, exploration and exploitation of natural resources[21]. Governments and civil society require efficient support establishing ethical and transparent procedures to manage subsoil, by improving the ability of effective research methods, regenerating the natural reserve base and ensuring that the resources are being well managed, taken into account their availability and scarcity, as well as the needs of present and future generations, without jeopardizing the use of the latter[21]. More and more in often practice, projects have to consider features such as natural and geographical distribution (that is not even in most cases), exhaustibility and non-replenish ability. The world is already filled with problems, and in order to avoid other social conflicts, geoethical principles must be employed in decision-making, especially at executive level.

Geoscientist must adopt an ethical behaviour within their own community. Educating the society about eco-friendly and prudent use of natural resources is almost as a duty to geoscientists. The pursuit of scientific research is one of their main objectives, and it is of their responsibility the dissemination of results, mainly if those results have the potential to affect positively the civil society. Active role in predicting geohazards, as well as proposing remediation to it and informing the population about them, while promoting preparedness to face geohazards like, earthquakes, floods, volcanos or landslides for example, are another geoethical activities of scientists. And finally, they must contribute in decision-making processes that involve directly interactions with the Geosphere, such as mining, groundwater use or geohazards[20].

Any kind of project should consider several multidisciplinary aspects, such as anthropologic, archeologic or historic studies, that are able to show the impact of the mining activity and the changes it caused in the lifestyle in the exploitation site and its surrounding community, allowing to understand the different aspects of the mining culture[21].

For the present case, Geoethics contemplate six sub-criteria (see Table 3.13).

The first concern related to Geoethics in this case is the preservation of the geological and mining heritage. To support and defend the past is fundamental to face the future with clear perspectives of progress[21]. The geological and mining heritage include many things: the natural and anthropogenic landscape, geologic structures with high scientific interest, buildings and facilities used during the activity of the mine, or technology documenting the various stage of the mine. All of those things have physic presence, but there is something else. Something that is not tangible. We are talking about the identity of the region, that include all the elements of the social life and cultural aspects that are in some way connected to mine, its activity and the people involved. Traditions, religion, beliefs, idioms, music, food are examples of aspects that define the identity of a region that must be preserved after the closure of the mine. Every element that can be seen as a resource to be integrated in the patrimonial set should be known and utilized in that sense, in every stage of the cycle of the mine. The valorisation of the heritage isn't something exclusive to the closure of the mine. The mining operation history can be reconstructed through several elements, and every one of them is important to that objective. The mining structures and facilities are one of the most relevant element. Following a previous selecting study stage, the rehabilitation of mines' equipment and facilities is to be considered. Their rehabilitation is a relevant objective in post-mining interventions, since they can give a historical perspective of the and sometimes a new use.

In a mine, it is expected to find geological points of interest, because the geologic formations where the ore is, are usually associated with specific phenomes that are represented in minerals, rocks, fossils and geological structures. Samples should be collected for future studies. Archaeology is another common topic in mining, since it is not unusual to find archaeological remains during the processes, remains that might possess great value for the scientific community, so they must be treated extremely carefully, in order to avoid any damage, otherwise potential breakthroughs can be lost forever.

It is a fact that the closure of a mine carries big impacts in the region, especially economically. However, it can represent a great opportunity for the promotion of culture and tourism. The creation of museums associated with this kind of project is a great way to valorise the patrimony, and also a potential source of revenue with the ability to promote other business initiatives in an area that is being affected by the ending of its most predominant activity. Another possibility, is the creation of geoparks or mining parks. Like museums, these parks constitute an important alternative for the sustainable development of any declining community. They allow the conservation of the patrimony and help to stop the possible degrading of the environment, while being a very good tool to show to people the importance of the mining activity on the supply of natural geological resources and its impact on the quality of life, as well as promoting geologic points of interest[22]. We can go even further, and develop one or more itineraries with recreational, cultural and historical purposes, with the possibility of including it in a wider touristic route, at regional or national scale. That would represent another point in favour of the tourism of the region.

Safety and health is a transversal subject in any field on Ethics and in Geoethics is no different. We can approach this topic in the three different ways. Firstly, we have safety and health at work. The mining activity is an activity that carries many potential risks to the integrity of the workers, just like: problems of subsidence, explosions, silicosis, and exposure to toxic or radioactive substances. It is imperative that the most actualized norms are being followed in order to reduce accidents or injuries to the minimum possible. Next, there is the safety of the community. The processes that are being conducted in the mine can bring problems to the population on the surroundings, and one of the main focus in an intervention is to evaluate how's the safety of community, assess the possibility of hazards and find solutions to remediate the existing problems. This is not something to consider only at a short term. The area must be monitored and controlled to evaluate the levels of safety after longs periods of time after the execution of the intervention is finished. Lastly, there is also the safety of the ecosystems, meaning that, from the Geoethical point of view, the rehabilitation project must take into account the negative environmental impacts and promote options that will improve the ecosystem balance.

Scenic quality is something priceless, with a unique and intrinsic value. The evaluation of the visual aspects of a landscape is subjective to every observer, depending on the elements that are present, such as geomorphologic or biotic elements. However, its value is an objective criterion and its valuation can be done in various ways. Generally speaking, four aspects can be considered to evaluate it[22]:

- Intrinsic characteristics of the site, that consist in the value and the complexity and contrast of terrain. It can be mountain, plain, valley, plateau…
- The contextual features that include naturalness (level of human intervention on the area), singularity (particular character or unusual of the place), diversity (number of the different elements present) and spectacularity (how a certain element captures the observer attention and interest).
- Visual possibilities refer to the visual field, visibility from other places and panoramic views.
- Presence of geologic points of interest or water courses, to be conserved.
-

The population plays a vital role in the development and execution of an intervention. It is important to present the project to the community, so it can be properly accepted by the people of the region and consequently get an active participation as well as all the needed support, by all sectors. The community must feel that the project is something that also belongs to them, and that their efforts are worth. This is usually not easy, because pleasing everyone is a hard task [8]. Public opinion is a very relevant aspect to be considered when defining the terms of the project and during its execution. Besides safety, that was already discussed, the main objective in the population criterion is the improvement of the quality of life. An intervention that does not bring any benefit to the population is not a good alternative. One of the most obvious benefits is the creation of new jobs. The intervention represents an opportunity to develop new activities in the region and with that, raise the employment opportunities. There is also the concern of helping former mines after the mine closure. For most of them, a big part of their life was spent working in a mine, it was their profession for years. Helping them to find a new role in the society by providing the necessary tools is something that needs to be considered.

The final sub-criterion is the strand of knowledge. One of the big objectives of Geoethics is related with the diffusion of knowledge and the mining activity is a great source of it. The promotion of action to appeal about the protection and defence of the geologic and mining patrimony is something necessary, and can be done through courses, conferences or even informative lectures on schools. It is important to educate the people about the issues related with mining and ways of acting in the area, so that the negative image that a lot of people have can be changed. It is also important to alert the society that exploitation of resources is a fundamental activity for the proper functioning of the modern society. Nevertheless, it is also important that everyone realizes, especially the younger generations, that the Earth's resources are finite and the only solution to face this reality is to adopt a sustainable behaviour because we only have one planet. The geoparks, previously mentioned, serve as a tool with pedagogic purposes, helping in the environmental education, in research associated with the geosciences and relevant environmental issues, and in the sustainable development[22]. The Research and Innovation is very significant in the mining activity, since a lot of studies can be performed, and their results can be very important breakthroughs at economic, social or technology level. Last but not least, there is the need safeguard knowledge of the present and past, so that future generations can improve even more, understand how things work or can be used to work and learn with past mistakes, that is, simply, "Knowing the past, to understand the present and plan the future".

Table 3.13 Geoethical Criteria

<table>
<tr><th colspan="8">GEOETHICAL CRITERIA</th></tr>
<tr><th colspan="2" rowspan="2">SUB-CRITERIA</th><th colspan="2" rowspan="2">ATRIBUTES</th><th rowspan="2">DESCRIPTION</th><th colspan="2">EVALUATION</th><th>UNITS/SCALE</th></tr>
<tr><th>Qualitative</th><th>Quantitative</th><th>Suggestion</th></tr>
<tr><td rowspan="5">3.1</td><td rowspan="5">Preservation of the geo-logical and mining herit-age</td><td>3.1.1</td><td>Identity of the region</td><td>Set of cultural aspects and socail life elements of the region that have any kind of conection with the mining activity</td><td>X</td><td></td><td>Traditions, mores, beliefs, religion, language, music, food, crafts…</td></tr>
<tr><td>3.1.2</td><td>Geological points of interest</td><td>Existence of geological sites with interest to education or preservation and the importance of that. Examples are: outcrops, geologic structures, terrain shapes, geologic landscapes, fossils, etc.</td><td>X</td><td></td><td>Rarity, representativeness, variety</td></tr>
<tr><td>3.1.3</td><td>Archaeology</td><td>Existence of archeological remains and the importance of them.</td><td>X</td><td></td><td>Presence and spatial distribution</td></tr>
<tr><td>3.1.4</td><td>Mining operation history</td><td>Elements that contributed to mining history and/or were relevant in the past.</td><td>X</td><td></td><td>Evaluate relevance</td></tr>
<tr><td>3.1.5</td><td>Rehabiliation of mining structures and facilities</td><td>Degree of intervention to recover the buildings.</td><td>X</td><td></td><td>Small, medium and high</td></tr>
<tr><td rowspan="3">3.2</td><td rowspan="3">Promotion of culture and tourism</td><td>3.2.1</td><td>Creation of museums</td><td>If there is the possibility to create a museum</td><td>X</td><td></td><td rowspan="2">Yes
No</td></tr>
<tr><td>3.2.2</td><td>Creation of a mining park/geopark</td><td>If there is the possibility to create mining park</td><td>X</td><td></td></tr>
<tr><td>3.2.3</td><td>Development of itineraries with cultural, historical and recreation interest</td><td>Possibility to include in the mining complex a touristic/educational route and/or to include in a wider tourisc route (regional or national scale)</td><td>X</td><td></td><td>None, one or more.</td></tr>
<tr><td rowspan="2">3.3</td><td rowspan="2">Safety and health</td><td>3.3.1</td><td>Safety and Health at Work</td><td>Safety, health, and welfare of people at the workplace</td><td>X</td><td></td><td>ISO 45001 standards</td></tr>
<tr><td>3.3.2</td><td>Safety of the community (short, medium and long term)</td><td>Understand if the mining activity is causing any damage to the population's health, so that the intervention can remove (or at least minimize that damage), without compromising anything else.</td><td>X</td><td></td><td>Level of safetyness (very safe, safe, not safe, dangerous)</td></tr>
</table>

GEOETHICAL CRITERIA							
SUB-CRITERIA		ATRIBUTES		DESCRIPTION	EVALUATION		UNITS/SCALE
					Qualitative	Quantitative	*Suggestion*
		3.3.3	Safety of the ecossystems	Understand if the mining activity had negative impact in the surrounding ecossystems and if so, the intervention must try to reverse he situation without raising any other problems	X		
3.4	**Scenic Quality**	**3.4.1**	Intrinsic characteristics of the site	Value of the landscape at the surrouding of the mining complex. Complexety and contrast of the terrain (relief)	X		Mountain, plateuau, plain, valley.
		3.4.2	Contextual features	Naturalness, singularity, diversity and spectacularity.	X		1 to 5 classification
		3.4.3	Visual possibilites	It refers to the visual field, visibility from other places and panoramic views.	X		
		3.4.4	Presence of important elements to be conserved	Geologic point of interest or water courses	X		None, small or high number of elements.
3.5	**Population**	**3.5.1**	Improvement of quality of life	Will any solution improve the qualitity of life?	X		Yes / No
		3.5.2	Role of the population in the intervention and public opinion	The benefits of the inclusion of public opinion and local community in the rehabilitation/reualification process.	X		Not beneficial, neutral, slightly beneficial, beneficial, very beneficial, essential
		3.5.3	Help former miners reintegrate in the life of the community after the closure of the mine.	Find ways to reintegate people that have been on mining sector their whole life in society, providing them tools so they can be assigned with new roles in the community.	X		Sucessufully, slightly sucessfully, unsucessfully
		3.5.4	Employment opportunities	Creation of new jobs.	X		Many opportunities, few opportunities, no opportunities.
3.6	**Strand of Knowledge**	**3.6.1**	Didatic/Educatinal purposes	The kind of educational content that can be developed and to targeted public.	X		Geology, stratigraphy, geomorphology, paleontology, etc..

		3.6.2	Scientific research potential	What aspects are there that enhance R&I and apply scientific research?	X		Very high, high, medium, low, very low, none
		3.6.3	Safeguard of knowledge for present and future generations	The level of need (Significance) to preserve and to leave the knowledge and history of that site for future generations.	X		Not significant, neutral, slightly significant, significant, very significant, essential

3.4. Technical issues

The abandoned mine regions present several safety and environmental issues, raised due to altered topography and poor management of mine wastes. Common problems include slope instability, water contamination, hydrological impacts, or even poor aesthetics. These problems are eliminated, or at least, reduced with the right reclamation plan[1]. In the most part of the cases, it is impossible to accomplish proper results in the selected post-mining land use without resorting to engineering solutions. Engineering tools provide a vision over the problem highlighting issues that are normally not spotted. Different kind of solutions can then be proposed, always considering the previous criteria: economic, environmental and geoethics, and trying to conciliate the objectives of each one without raising any concerns. Furthermore, the feasibility of the processes needed to execute the intervention is evaluated, allowing an optimization of the project.

The planning of mining revitalization project is a multidisciplinary task, that requires the contribution of several experts from various fields of technology, such as managers, engineers, risk analysts and others. The goal is to select methods that are techno and economically feasible with low risk regarding sustainability for each site-specific case. Those projects are often linked with numerous risk and uncertainties related to natural and technological parameters[23]. The selection of a certain technique or methodology of evaluation has to consider the characteristics of the problem: number of variables e actions, quantity and quality of data, etc.; as well as the objectives and if it can cover the totality of the problem or just part of it.

The project should consider not only the impacts that resulted from the years where the mine was active but also the impacts caused by its closure and the time after that, always considering the small and big term when proposing solutions. These solutions can be preventive, if the goal is to avoid the (negative) effect of a determined source; or corrective if the objective is to mitigate totally or partially the damage and changes done to the site. In order to determine the most effective measures to apply, every source of negative impact should be analysed, trying to find the most adequate actions to take (preventive or corrective)[15].

There are six criteria for evaluating the technical issues, which are described below (see Table 3.14).

- Physical characteristics of the mine: this includes mine dimensions, all the areas affected by the activity of the mine, including galleries and works in depth, mining structures and facilities, waste dumps, tailings dams, waste rock heaps and other types of wastes facilities; the surrounding area of mine complex and the accessibility to it. The effects in all those areas should be identified, classified and quantified. Other relevant physical characteristics are the typology of the exploitation (superficial, underground or both) and its historical characteristics.

- Contamination: this is one of the biggest concerns related to mining. We have two main relevant types of contamination: water contamination, and soil and sediment contamination. In the case of the water, the contamination can be at the surface level or in groundwater. Contamination sources control and, in most of the cases, contamination treatment is mandatory. Other relevant feature is mine waste, its type, characteristics and how they were or are being deposited. During the mining processes occurs the production of inert wastes and also wastes that may contain certain quantities of hazardous substances. Waste require treatment, secure disposal and monitoring.
- Mining structures and facilities: it is necessary to evaluate the conditions of mining structures and facilities in order to understand how much improvements will be required to re-establish the safety requirements and to assess what can be re-used for another purpose after being rehabilitated. Besides that, there is also the need to evaluate the conditions of power, gas, water, and other indispensable services. The conditions of mine waste infrastructures must also be considered, such as stability conditions, drainage seepage, need for physical stability works (contamination is not included).
- Raw materials and circular economy: in this perspective it is intendent that the technical solution considers potential for the reutilisation of mining wastes during the rehabilitation process. It is a topic that is gaining more and more strength in the past years. The consumption of natural resources by our current society has grown into absurd proportions, it does not show signs of slowing down, and it is far from a sustainable stage. Being the mining industry a very relevant sector in the acquisition of raw materials it is fundamental that the circular economy ideals are presented. For each mine, remining waste potential should be assessed, with the possibility of re-opening it or reutilize the tailings or other materials in other projects, always considering the environmental impacts and economic feasibility.
- Geomorphology: includes morphology/topography characteristics, the assessment of the types of natural drainage systems present in the surrounding area, the landform of the mine waste deposits, and the new landform requirements to suit the selected the post-mining land use. Lastly, comes stability and risk conditions. This parameter contemplates the stability of slopes of the mine measured using the factor of safety; earthmoving (usually associated to new landform); subsidence; and other geologic/geotechnical and natural hazards, including those resulting from climate change, taking into consideration accessibility to mine site.

Table 3.14 Technical issues Criteria

THECHNICAL ISSUES CRITERIA							
SUB-CRITERIA		ATRIBUTES		DESCRIPTION	EVALUATION		UNITS/SCALE
					Qualitative	Quantitative	*Suggestion*
4.1	**Mine physical characteristics**	**4.1.1**	Interventional area characteristics	Mine dimension (total area ocupied by the mine); affected mining area (includes the area afected by galleries and depth of mining works, open pit, mining structures, waste dumps, tailings dams, waste rock heaps, and other types of wastes facilities); affected sorrounding area (includes the effects on sorrounding envionment and land of the mine complex) and accessbility (the level of accessbility to the mining area, the type of access and their conditions.).	X	X	Area, type of effect and access.
		4.1.2	Typology of exploitation	Existence of superficial (only open pits), underground or superficial+underground and its historical characteristics	X		Superficial, underground, both
		4.1.3	Historical processes characteristics	Type of mining processess and ores exploited used in the past.	X		1-5 scale
4.2	**Contamination typology**	**4.2.1**	Water contamination	Surface water and groundwater. Existence of contamination and needs for treatment and monitoring of water and sources of contamination. Mine water drainage/contamination, mine water treatment potentialities. Water treatment systems (Passive /Active)		X	pH, conductivity, redox potential, dissolved oxygen, TSS (total solids in suspension/ water turbidity), colour
		4.2.2	Soil and sediment contamination	Existence of contamination and needs for treatment and monitoring of soil and sources of contamination. Soil treatment and/or refreshment.	X	X	Gamma radiation, geochemical and radiological indicators.
		4.2.3	Mine wastes types	Wastes produced during the mine activity, that contain hazardous substances, and therefore require tratment, secure disposal and monitoring.	X		Waste rock, tailings, sludges, sulphide wastes, urban wastes, water

THECHNICAL ISSUES CRITERIA							
SUB-CRITERIA		**ATRIBUTES**		**DESCRIPTION**	**EVALUATION**		**UNITS/SCALE**
					Qualitative	**Quantitative**	***Suggestion***
4.3	**Mining structures and facilities**	**4.3.1**	Conditions of the mining building and faciliteies	Condition of the buildings in terms of safety and level of intervention needs	X		Remove. Strong, minor or no need for improvements.
		4.3.2	Re-use/Recycling of structures or facilites	Give new use to old strucutures or facilities	X		Not possible, possible with several or few adjustments.
		4.3.3	Conditions of power, gas, water, etc infrastructures	Condition of the power, gas and water facilities.	X		Remove. Need strong, minor or no need for improvements.
		4.3.4	Conditions of the mine waste infrastructures	Stability conditions, drainage seepage, need for physical stability works in tailing dum, heap leaching and, waste deposits. (Note: contamination is not included)	X		
4.4	**Raw materials and circular economy**	**4.4.1**	Remining potencial	Remining environmental and economic impact. Possibility for a re-opening of the mine works or reutilize the tailings, its environmental impacts and economic feasibility.	X		Yes/No
		4.4.2	Mine Waste management strategy	The potential to use some waste (any type) in other activities or locations. Possibility of associating the intervention to other mining projects, i.e, transfer of waste that can be used in another mining areas.	X		
4.5	**Geomorphology**	**4.5.1**	Morphologyl/topography characteristics	The type of geographical relief, the existance of valeys, mountains, plain in the mining complex or in the surroundings.	X		Yes/No
		4.5.2	Natural drainage system	Assessment of the type of natural drainage system, the impreventions performed and what needs to be done and the evaluation of water permeability.	X		Surface, subsurface, both. Rivers, lakes, swamps
		4.5.3	Landform of mine waste deposits	Evaluate the way the landform/morfphology of the mine wate diposits may influence the option for the land use. Assess the level of intervention to minimise the negative impacts.	X		1-5 scale
		4.5.4	New landform requirments	The desirable landform suitable for the selected post-mining land use.	X		Yes/No

THECHNICAL ISSUES CRITERIA							
SUB-CRITERIA		**ATRIBUTES**		**DESCRIPTION**	**EVALUATION**		**UNITS/SCALE**
					Qualitative	**Quantitative**	***Suggestion***
4.6	**Stability and risk conditions**	**4.6.1**	Stability of slopes of the mine	Condition of inclined soil or rock slopes to withstand or undergo movement.		X	Factor of safety
		4.6.2	Earthmoving	Is there the need for earthmoving? Bring topsoil from other adjacent locations or to place it in adjacent areas.	X		Yes/No
		4.6.3	Subsidence	Settlement criteria suitable for future use and risks to surface infrastructure.	X		
		4.6.4	Other geologic/geotechnical and natural hazards	Earthquakes, other natural hazards, including the ones from climate change, taking into considerations the accessbility to mine site.	X		

3.5. Potential for Regional Development

A mine can have a very significant impact in the development of the region in which it is inserted and in its surrounding areas. The contribution to the economic development in the region provided by mining activity proves to be an important factor when it comes to the relations between mine and local community. In each case, the circumstances will be different, affected by aspects like the mine dimensions, its localization, what kind of materials are being exploited, etc. This is an industry that is usually dominant in the area where is operating, and, because of that, plays a huge role in providing jobs locally and generating income, creating an economic dependency in these mining communities. After the closure of a local representative mine, many changes will occur to the life in the region, which should be accordingly with the Regional Smart Specialisations Strategies (RIS3) defined by, and for, the region.

The distribution of costs and benefits does not occur in the same way, at different scales. While at a more global scale, the balance is essentially positive because the resources that are explored represent essential assets to the society, mostly because of its unique nature, allowing the development of numerous technologies, bringing benefits to society; at a national level, the tendency is not the same. It's a fact that the revenues from the mining industry have a big contribution for the development of infra-structures and economic power, being also a platform for the growth of the industrial sector and other important activities. However, there is a negative side, mining's economic power created distortions on the economic, social and political aspect of some countries, generating conditions in which corruption and culture of dependency may take root[14]. Meanwhile, at a local level the scenario tends to be negative. The closure and abandon of the mine resulted in polluted sites, very degraded infra-structures, economic contraction, leading to lack of capacity to start or transition to another activity, and a reduction of the communities' population by emigration[14]. The emigration is relevant topic when discussing this criterion. Normally, the mining communities are formed and expanded when economic opportunities are created through immigration. However, those same communities shrink or even disappear when the opportunities are low or absent. This phenome does not contribute to the social stability required so the communities become stronger against socioeconomic changes. Besides that, the people that emigrate are the ones who possess high value knowledge and skills, leaving the rest of the community less entrepreneurial, and as a consequence less able to identify other sustainable alternatives[14].

Other aspect to consider is the regulations implemented by the governments in the mining industry. These regulations are not proactive, making the delivery of improvements to take longer to be implemented. Even if there is a strong regulatory framework, the enforcement is weak most of the times, or even absent, at a local level.

There are very examples of post-mining projects that were able to obtain funds outside the mining sector. Creativity and expertise in fund-raising is what needs to be encouraged. The problem is not related with the shortage of potential funding organisations to deal with post-mining issues. What is lacking in many cases is the vision of desired results that are meant to achieve through the regeneration process, around which a diverse group of potential donors can be gathered in order to solve specific post-mining situations in certain sites or regions[14].

The aim of the post-mining land use is not only the ecological revitalisation of the area but also, if possible, the socio-economical rehabilitation of the region.

The Potential for Regional Development (PRD) criterion aims at assessing the impact of each revitalisation alternative in several economic activities that may contribute to regional developments, considering at the same time the legal framework and proximity to local populations.

In order to do so, PRD is divided into six sub-criterions (see Table 3.15).

The agricultural potential (for example: pasture, plantations, biological agriculture…); commercial potential, where the post-mining land use can result in the creation of new commercial activities or promote the growth of existing activities; touristic potential, as a result of an intervention that made the area an appealing destination for holidays; real estate potential, by creating new residential zones or promoting the growth and appreciation of existing ones; legislation and legal framework, because the intervention has to follow the legal requisites of the region; and the proximity to local populations or other points of interest to the mine's rehabilitation project.

Table 3.15 Potential Regional Development

POTENTIAL REGIONAL DEVELOPMENT							
SUB-CRITERIA		ATRIBUTES		DESCRIPTION	EVALUATION		UNITS/SCALE
					Qualitative	Quantitative	*Suggestion*
5.1	**Agricultural potential**		-	The potential for agriculture and what type of agriculture	X		Pasture, forest, plantations, cattle, biological agriculture, community gardens
5.2	**Commercial potential**		-	Promotion of new commercial activities and the type of them (reneable energy, local stores, regional and artisanal products) and growth of existing activities (and respetive revenues).	X		1 to 5 (weak to excellent)
5.3	**Touristic potential**		-	Appealing destination for holidays after the intervention by national or regional tourists or foreigners and the way it can be appealling (resort, nature walk, etc.).	X		Resort, nature, SPA, adventure
5.4	**Real estate potential**		-	Creation, growth and appreciation of residential areas.	X		Residential, touristic houses
5.5	**Legislations and legal framework**		-	What is aceptable and possible by the territorial management mechanisms (land use type). Appliable decrees and laws at EU level and for the ones specific for each country.Integration with Regional Smart Specialisations Strategy (RIS3).	X		1-5 scale based on what is feasible in the region
5.6	**Proximity**		-	Distance to local populations or other points of interest to the mine's rehabilitation project.	X		Very close, close, regular, distant, very distant

4. Case Study: Applying MCDA methods in a Portuguese mine – Urgeiriça

4.1. Urgeiriça mining area

The mining area of Urgeiriça is located south of Viseu, in the zone of Canas de Senhorim, county of Nelas, district of Viseu (Figure 4.9). Its access is done by Estrada Nacional nº234 and the railway line is near the mine. The mine is inside the village of Urgeiriça, which has two residential areas, one at north and the other at south, making a total of about 300 habitants. Urgeiriça is practically continuously with Canas de Senhorim, that has a population of 5000 habitants.

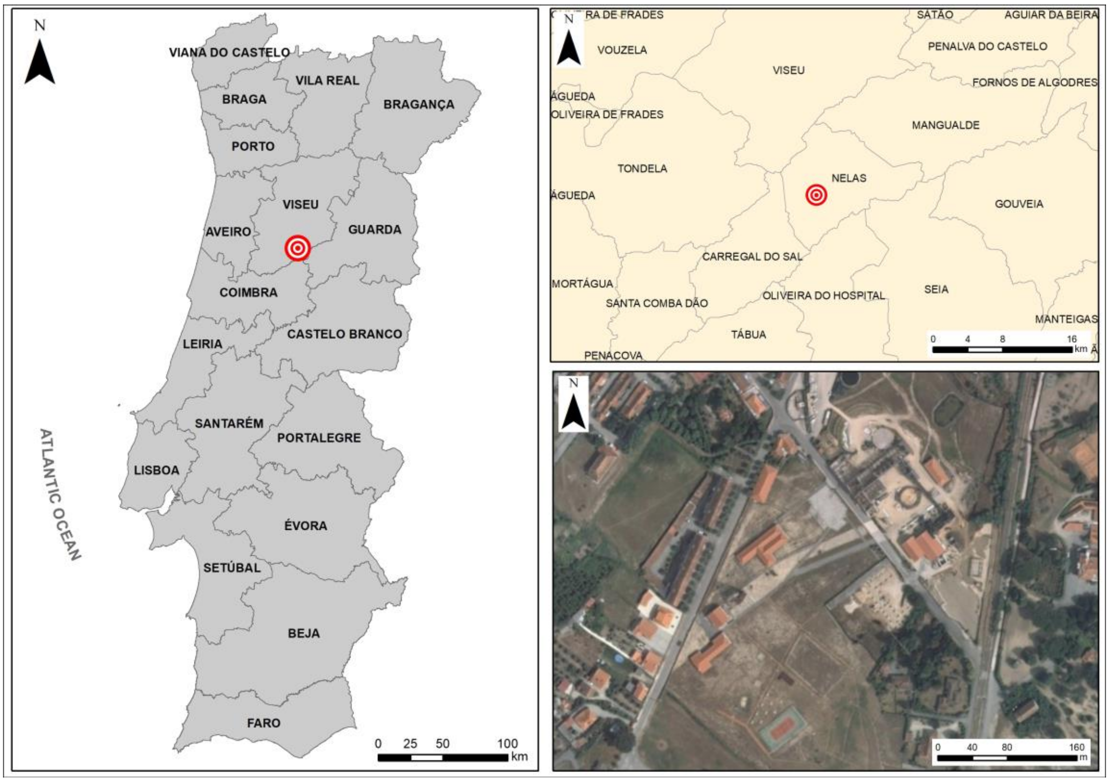


Figure 4.9 – Urgeiriça mining region location

4 km south is found the village of Caldas de Ferreira, where mineral water is explored to be used for medicinal purposes. A small portion of mining area belongs the extended protected perimeter of the aquifer related with the mineral water mentioned.

Urgeiriça mine was once considered one of the most important mineral deposit of Europe, begging its activity in the year of 1913, being the focus (exclusively until 1944) the production of uranium. The mine is constituted by 6 wells located along the mineralized area. The maximum depth of exploitation reached about 500 meters, with an horizontal extension of about 1600 meters, using 19 floors, each separated by 40 meters approximately.

The exploited areas reached a width in the order of 15-30 meters to each side of the mineralized fault, with some columns being left. In the wells and dismantle zones, some filling was made, with the exception of the main well and the main galleries.

In the early 50's the Chemical Treatment Workshop (CTW) was built, over an approximate area of 4,5 ha, and with the capacity of an annual production of U_3O_8 of 125 tons. In 1967, this unit was remodelled with the objective of improving the quality of the product and the increase the production to 200 tons a year. In 1970, the in situ static lixiviation exploration began, and in 1973 the conventional underground exploitation was ended. In the lixiviation process, the substances were collected in lower floors and then pumped to the surface, to be used in the CTW. The usage of this method came to a end in the year of 1991. Since its beginning, the CTW has produced about 4400 tons of uranium oxide, with 25% made using ore from Urgeiriça and remaining 75% from ore from other explored mining areas.

The tailings that resulted from the mining processing in the CTW were sent to two dams – Old Tailings Dam and New Tailings Dam. The chemical components resulting from the processes to concentrate uranium were equally deposited in the tailing dams. In the New Tailing Dam is located the neutralization and decontamination station of Urgeiriça, that receives the liquid effluents generated in the area.

In the late 90's, next to the mine's main well (Santa Bárbara Well) there was, since the 40's, a heap with about 1,5 ha and an approximate volume of 80.000m^3, that was located under a storage where the concentrate of uranium produced in Portugal was stored and not exported yet. There were, equally, another two heap leaching, with smaller dimensions, associated with old extraction wells. There was also a covered zone were ore brought from other mines that did not get to be used was stored.

Figure 4.10 - Urgeiriça mining area (Source: EDM)

In the early 2000’s environmental characterization studies were developed to analyse the reference situation of this mine and its surroundings under the "Radioactive Mineral Areas Director's Study", that included several topics such as hydrochemistry, geochemistry, radon levels on the atmosphere, etc. . The objective was to define an action plan that could tackle the problems raised after the mine closure and revitalize and rehabilitate the mining region. According to a recent study by EDM (Empresa de Desenvolvimento Mineiro), Urgeiriça is one of the Portuguese mines that require an intervention with more urgency. With that in mind, this mining region became the object of this study in this thesis.

4.2. Performance Matrix

One of the scopes of this thesis is the selection of a post-mining land use to be implemented in a specific post-mining region using an MCDA approach. In Chapter 4.1, the selected mining region was introduced and briefly described, and the purpose of this chapter is the classification of that region using the criteria that was established in Chapter 3. To do so, it is required to specify alternatives that will be classified regarding the criteria. For this case, six possible alternatives were considered:

- **Agriculture** – this includes arable farmland, garden, pasture or hay land and nursery. Agriculture is still a very reliable option on the current days, because it's an activity that has been evolving in the past years, adapting to newest technologies, leading to more optimized processes. The work develop by Pino et al (2020)[24], are a very good example; where the integration of drones in this sector allow for a higher efficiency and better performance – precision agriculture.
- **Forestry –** this alternative contemplates lumber production, which would represent a continuity of resource exploration/exploitation after the closure of the mine; and woodland, shrubs and native forestation, that create more green spaces and highly contribute for the region natural landscape.
- **Intensive Recreation** – related with sport and leisure activities, such as sport fields, sailing, swimming, fishing, hunting, and others. It can be great for the community of the region and there are many successful cases that followed this approach. The AXA Stadium, in Portugal, home Sporting Clube de Braga, also known as "a Pedreira", which translate to "the Quarry", is an easy example of this alternative.
- **Non-Intensive Recreation –** the promotion of culture and tourism are the main focus here, by creating parks (including geoparks) and open green spaces, and also museums or exhibition of old mining facilities or mining innovations.
- **Construction** – the name in self-explanatory in this case. The objective is to build new infrastructures (or try to use some of the old ones) in the place where the mine was. The building can have several purposes: residential, commercial (shopping centre), industrial (factory for example), educational (school or university), etc.
- **Conservation** – this option considers wildlife habitat and water supply. Both things tackle serious issues raised in the past years and that are a bigger concern to the global sustainability each year that passes.

After establishing the alternatives is now possible to build a performance matrix (alternatives vs criteria). For this, a big amount of information is necessary. In this classification several documents from the company EDM, gently provided by Professor Sofia Barbosa, were consulted. This documentation included descriptive memories, term of reference, mine estimates, mine plans, mine plants and other attachments.

The criteria take into account subjects of distinct areas and the information assumes different forms – quantitative, qualitative or mixed. Besides that, the data used in criteria can be beneficial, where the higher the value the better is the situation, like “safety” for example; or non-beneficial, which represent the opposite, that is, higher values represent worst scenarios, like costs. To address this situation, all data was normalized in a 1-5 scale where 1 is always the worst value and 5 the best. The criteria established in Chapter 3 was extremely detailed, The applied classification considers only the two first levels: criteria and sub-criteria.

Two fields of sub-criteria weren’t classified due to lack of information. They are “1.4 Mine closure Funding/Investment” and “5.5 Legislations and legal framework”. Its classification appears as zero (0) in the performance matrix and to its weights were attributed the value of 0 (will be seen in Chapter 4.3).

Below, is presented the Performance matrix, in Table 4.16 .

Table 4.16 - Performance Matrix

		Economic			
		Costs	Time	Post-mining economic balance	Mine closure funding investment
Alternatives	Agriculture	4	5	3	-
	Forestry	5	5	2	-
	Intensive Recreation	3	3	4	-
	Non-intensive Recreation	2	2	2	-
	Construction	1	2	5	-
	Conservation	4	4	1	-

		Environmental			
		Atmosphere	Aquatic	Terrestrial	Biological
Alternatives	Agriculture	4	3	4	3
	Forestry	5	4	4	4
	Intensive Recreation	3	3	2	2
	Non-intensive Recreation	4	3	4	3
	Construction	2	2	2	1
	Conservation	5	5	4	5

		Geoethics					
		Preservation (heritage)	Culture and tourism	Safety and health	Scenic Quality	Population	Knowledge
Alternatives	Agriculture	3	3	4	3	3	2
	Forestry	3	3	4	3	3	2
	Intensive Recreation	3	3	3	3	3	3
	Non-intensive Recreation	4	5	4	4	3	5
	Construction	2	2	3	2	4	4
	Conservation	4	2	5	5	2	3
		Engineering					
		Mine character-istics	Contamination	Mining struc-tures and facili-ties	Raw materials and circular economy	Geomorphology	Stability and risk
Alternatives	Agriculture	3	3	2	3	2	3
	Forestry	3	4	2	3	2	3
	Intensive Recreation	4	3	3	4	3	2
	Non-intensive Recreation	3	4	4	3	3	4
	Construction	4	2	3	5	4	3
	Conservation	3	5	4	2	2	3
		Potential Regional Development					
		Agricultural	Commercial	Touristic	Real estate	Legislations	Proximity
Alternatives	Agriculture	5	2	1	1	-	3
	Forestry	3	2	1	1	-	3
	Intensive Recreation	2	4	4	3	-	4
	Non-intensive Recreation	3	2	5	3	-	3
	Construction	1	5	4	4	-	5
	Conservation	3	1	2	2	-	2

4.3. Weight Scenarios

As it was stated previously, the weights applied in an MCDA model are very relevant to the results. It can be a complicated process and it must be done carefully. Usually, the stakeholders and decision-makers are the ones who establish the weights of the criteria, often with aid of experts on the field and always considering the objectives and interests of the project. Being this study, a situation where one of the goals is to evaluate and understand who valuable this tool (MCDA) can be when applied in this topic, there were considered nine (9) set of weights.

Different weighting methods were used, with a total of 5 different methods, 3 objective and 2 subjective. The subjective methods considered 3 scenarios each. Table contains the method that were used and a simple explanation of each one.

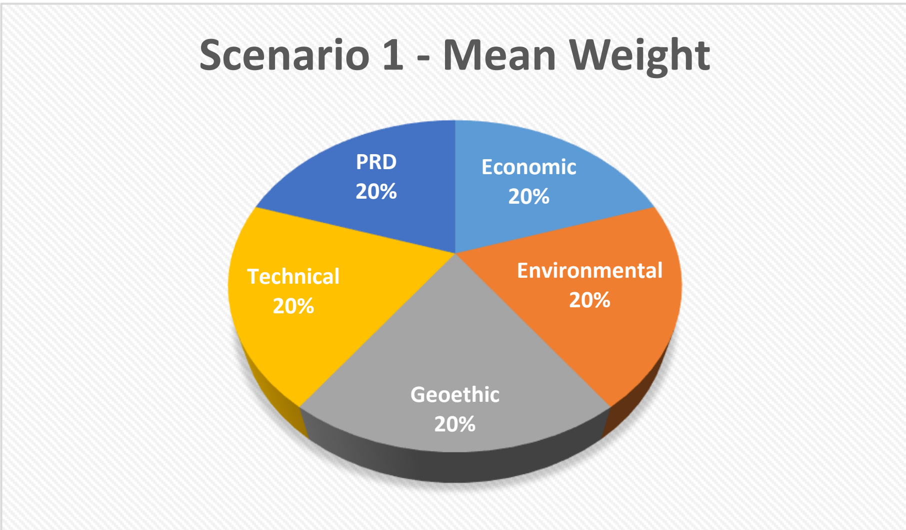
Table 4.17 - Weighting methods used

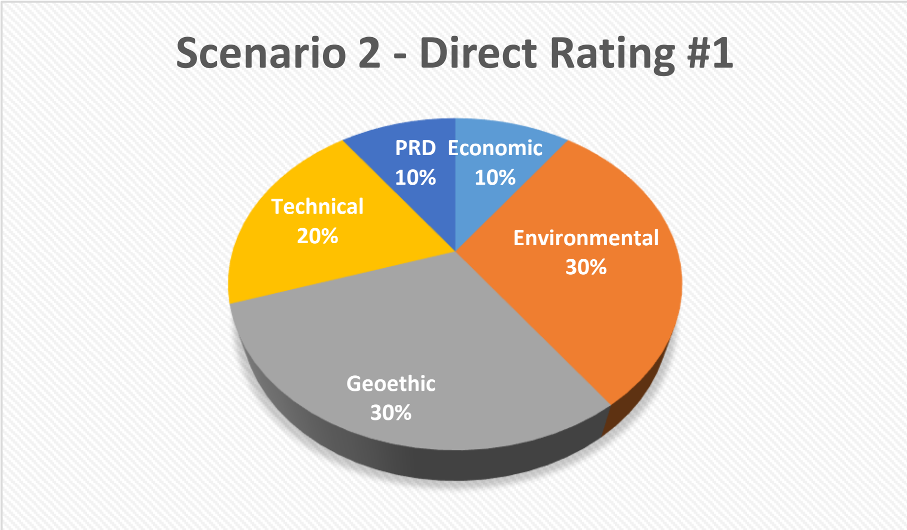
Method	Description
Mean Weight	The mean weight is based on the assumption that all criteria are of equal importance.
Direct Rating	The stakeholders or decision-makers assign number values to the different criteria.
Pairwise comparison (AHP)	The decision-maker compares each criterion with others and determines the level of preferences for each pair of such criteria.
Entropy	Assesses the relative importance of criteria using material data for each criterion in the calculations. Entropy in information theory is a criterion for the amount of uncertainty represented by a discrete probability distribution,
Standard Deviation	The weights of the criteria are determined in terms of their standard deviations.

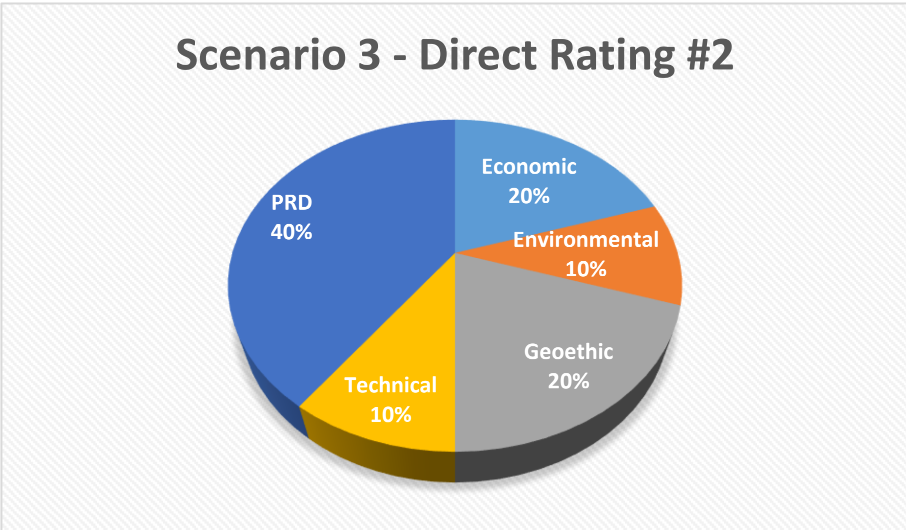
During the works of this thesis, only some of the presented weighting methods in Chapter 2.4 were used, for two main reasons. Firstly, there are many techniques and to test all of it would mean an extensive amount of testing, even bringing some counterproductivity, since only a small percentage of work would actually be presented in the dissertation. The second reason is related with the selection of the most adequate methods considering the problem that is being faced and its circumstances.

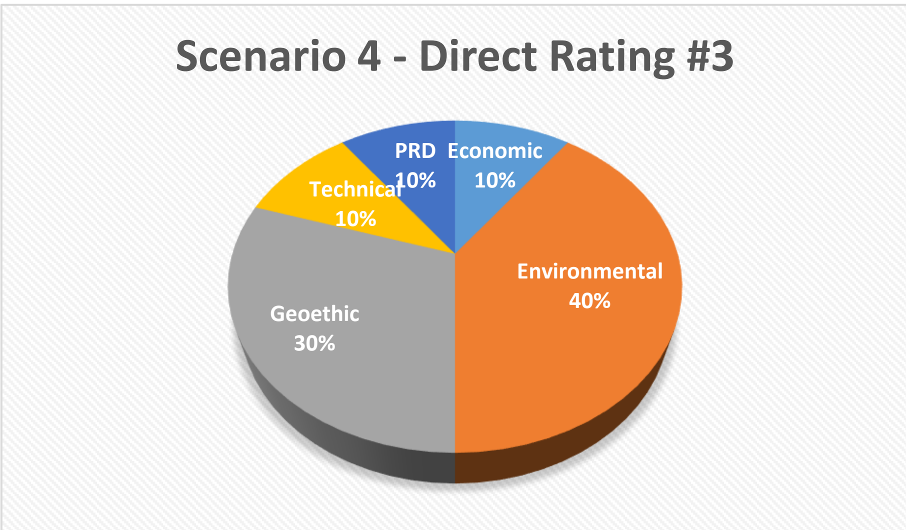
Distinct nine scenarios were created with the objective of recreating distinct possible and realistic situations that might be defined by stakeholders involved in the decisional process of the rehabilitation of the mine site. These scenarios also try to cover various possibilities of importance attributed to the established criteria, which means that in some scenarios criteria may have higher weights, and in other cases, lower weights one.

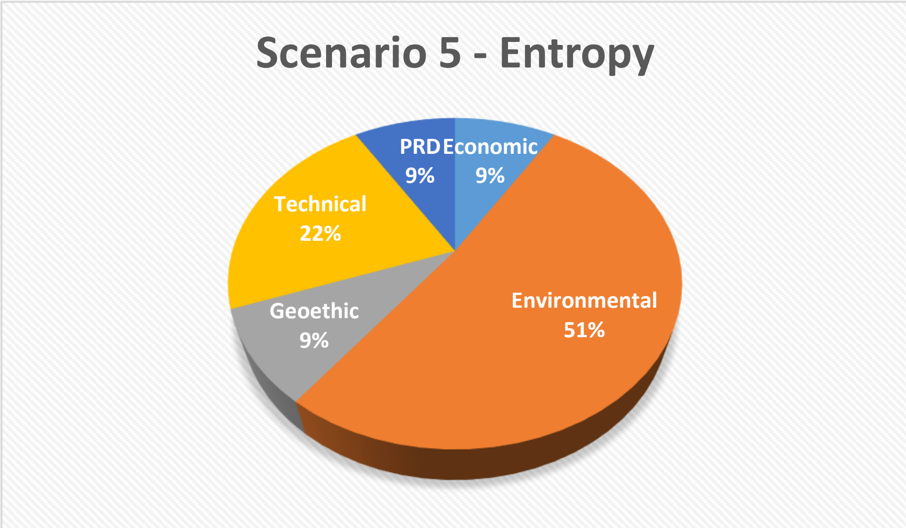
The graphics below in Figure 4.11 and 4.12, show distribution of weights in the nine scenarios.

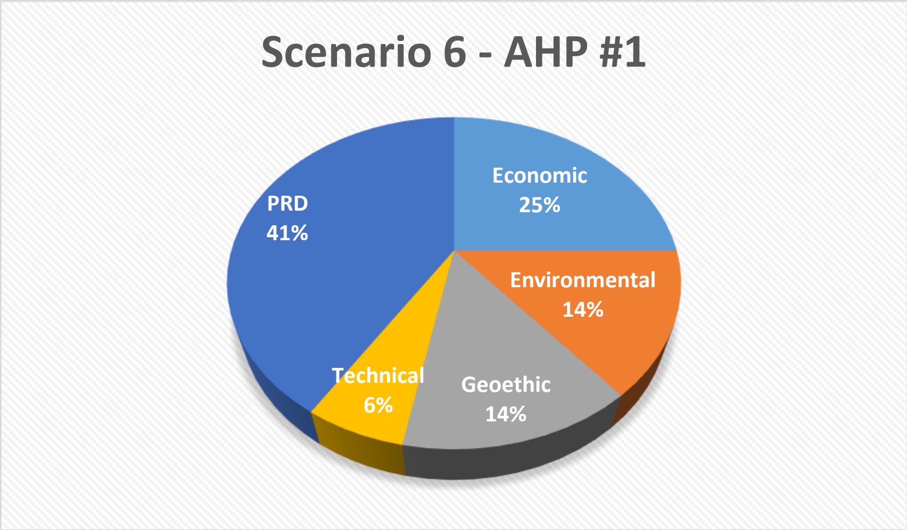


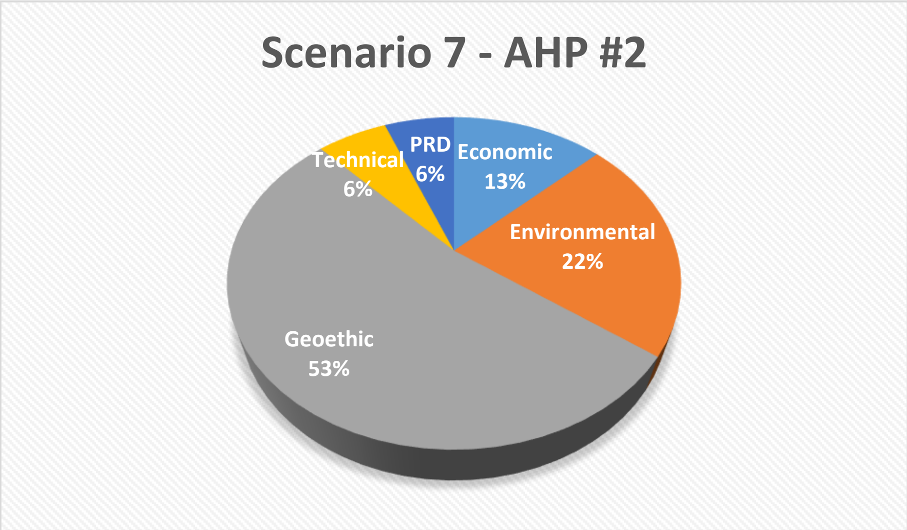

Scenario 2 - Direct Rating #1
PRD
10%
Economic
10%
Technical
20%
Environmental
30%
Geoethic
30%

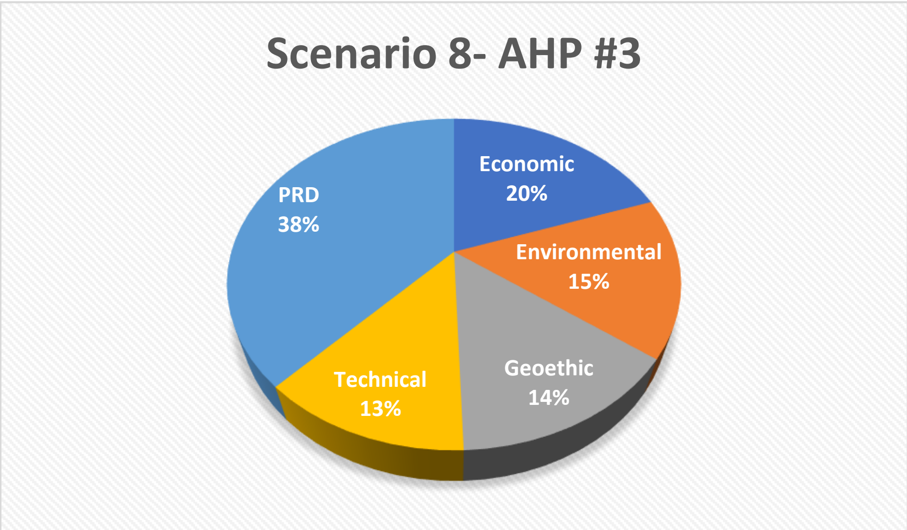

Scenario 3 - Direct Rating #2
Economic
20%
PRD
40%
Environmental
10%
Geoethic
20%
Technical
10%


Scenario 4 - Direct Rating #3
PRD
10%
Economic
10%
Technical
10%
Environmental
40%
Geoethic
30%


Scenario 5 - Entropy
PRD 9%
Economic 9%
Technical 22%
Geoethic 9%
Environmental 51%


Scenario 6 - AHP #1
PRD 41%
Economic 25%
Environmental 14%
Technical 6%
Geoethic 14%


Scenario 7 - AHP #2
Technical 6%
PRD 6%
Economic 13%
Environmental 22%
Geoethic 53%


Scenario 8- AHP #3
PRD 38%
Economic 20%
Environmental 15%
Technical 13%
Geoethic 14%

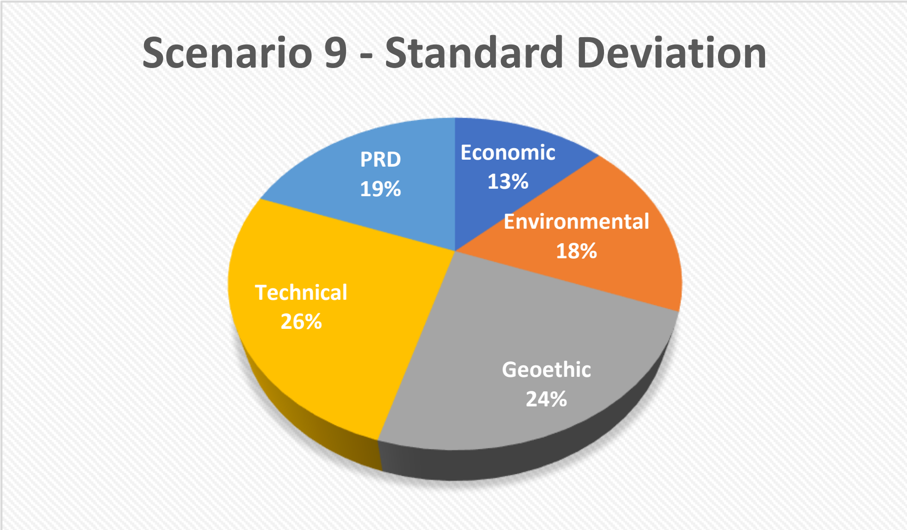


Figure 4.11 - Weight Scenarios

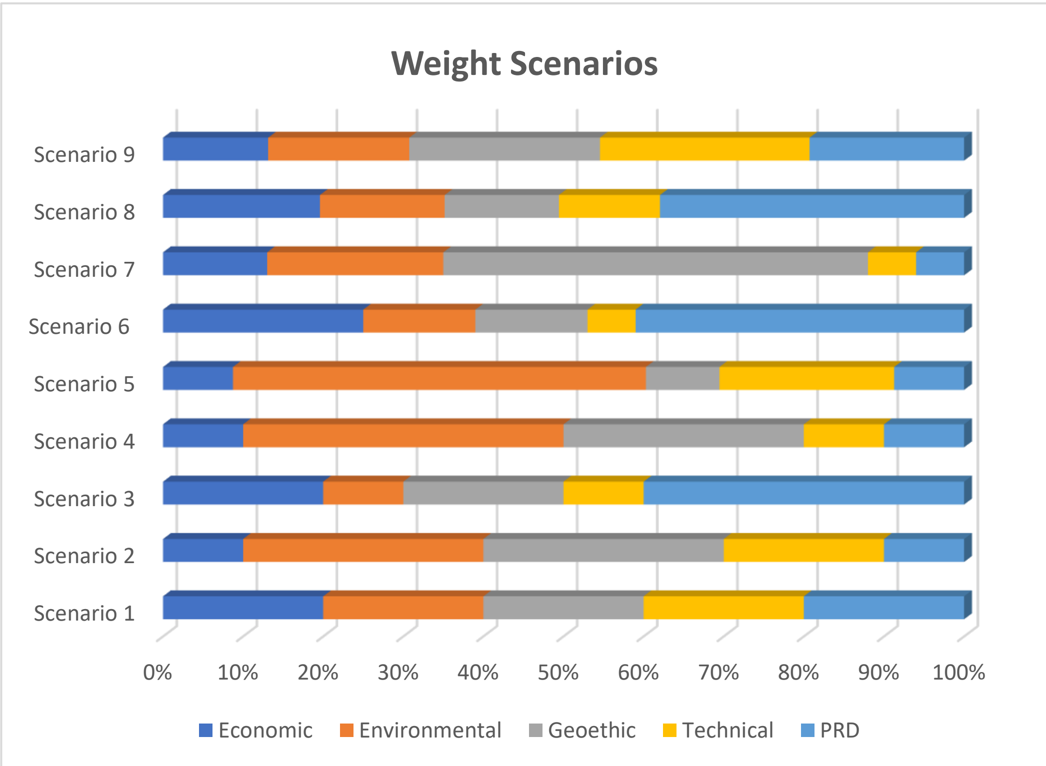


Figure 4.12 – Comparison between weight scenarios

4.4. Applying MCDA methods

Once the alternatives and criteria are defined, it is possible to begin the next of the process: the application of an MCDA method. In Chapter 2.5, a comparison was made highlighting the differences between various techniques. Based on that comparison, various methods were selected to be applied in the case study.

Two (2) full aggregation method were selected, WSM – Weight Sum Model (from MAUT) and AHP. TOPSIS and VIKOR, that belong to the goal, aspiration or reference level were also selected. The outranking family does not have any representation on this study, because the definition of thresholds requires more expertise and a larger amount of information, and to define those parameters in an accurate way won't be beneficial for the study. MACBETH and ANP were described previously but they were not used in this study. The first requires a specific software to compute the model or a more advanced programming, unlike the other methods that were used. ANP, as it was stated, before uses three types of dependencies in order to build the super matrix. That process is a task for more advanced users of this MCDM method, and is also an exhaustive and hard procedure, especially considering that the established criteria can be considered independent without compromising the effectiveness of the study and robustness of the model.

All the MCDA methods selected in this dissertation were applied using Microsoft Excel. After the concepts and "black-boxes" were understood it became possible to implement the referred methods using various functions in order to programme each technique.

4.4.1 Applying WSM

The Weight Sum Model is arguably the most simple and widely-known method of Multi-Criteria problems, since it only consists in the summation of the products between all alternatives and criterions. Figure 4.12 shows the results obtained using WSM.

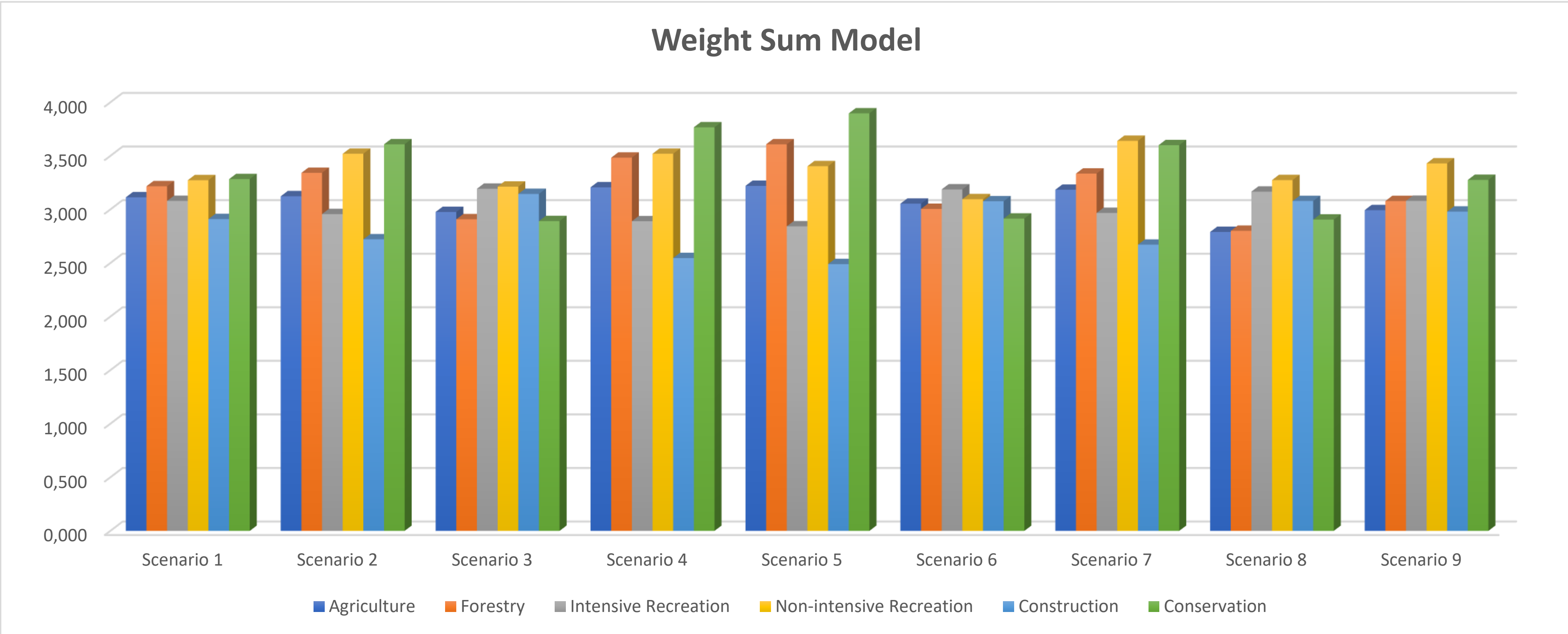


Figure 4.13 - WSM Results

A considerable amount of information can be obtained by analysing the Figure 4.12:

- Scenario 1 shows some balance between all alternatives which reflects a balanced classification. However, *forestry*, *non-intensive recreation* and c*onservation* take a slightly advantage relatively to the other three alternatives, with the two last ones having the highest score.
- In Scenario 2, the situation is different. The top 3 alternatives in the previous scenario distance themselves even more from the bottom 3, with *conservation* assuming an evident lead.
- In Scenario 3 and 6, very likewise to the first scenario the alternatives are moss or less balanced, with approximate scores between themselves. The two types of *recreation* and *construction* are the more rated option in these scenarios.
- Scenario 4 and 5 have a similar pattern, where *Conservation* ais the highest score of the six alternatives. It is followed by *N. I. Recreation* and then *Forestry* in Scenario 4, happening the opposite in Scenario 5. The remaining three alternatives follow the order *Agriculture – I. Recreation – Construction* in both scenarios.
- Scenario 7 is not very different from the previous scenarios, but *N.I. Recreation* secures the top spot, trading places with *Conservation* that falls to second best alternative. The other options follow the same order as in the last point.
- In Scenario 8, the scores have almost the same difference in scores between consecutive places, with *N.I. Recreation* with the highest one. *Agricultural* and *Forestry*, however, have the lowest scores, being both very identical, in opposition to the difference verified between the other alternatives.
- Finally, Scenario 9 shows some balance among the four alternatives with lower scores, with *N.I. Recreation* and *Conservation* standing out from the rest, with the first having an evident advantage over the latter.

Generally speaking, it’s easy to observe that two alternatives tend to have higher scores in most of the scenarios: *N.I. Recreation* and *Conservation*, and in most of the times they stand out very evidently from the rest. There is only one Scenarios where neither of those two is the highest ranked alternative – Scenario 6, where *I. Recreation* takes the first place. On the other hand, *Construction* seems to fall behind most of times, never reaching the top spot. In Scenario 3 and 6, where it’s closer to the top, all the alternatives are very close between themselves.

4.4.2 Applying AHP

AHP is probably the most talked method when the topic is MCDA. It was one of the first great methods that came up and it's used very often in the most distinct fields and situations. The results obtained using this method can be seen in Figure 4.13.

By analysing the graphs some things can be observed in a first look. The tendency where *N.I. Recreation* and *Conservation* are the predominant alternatives is also present when using AHP, but it's not as clear as while using WSM. Other thing to highlight it's the absence of more balanced scenarios; in each Scenarios there's always alternatives standing out from the rest, while others clearly fall behind, especially *Construction*. This alternative is closer to the top in the same scenarios as in the WSM results – Scenarios 3 and 8. The more balanced scenario is probably Scenario 1, and even in that situation the difference between the highest and lowest ranked alternatives is considerable. This balance is explained by the weight equality in this scenario since the classification of the various alternatives is overall balanced as well.

Scenario 5 presents an interesting occurrence: it's simultaneously the scenario with the highest value registered (*Conservation*) and the lowest one (*Construction*), which means that is also the scenario with the biggest gap between the best and worst alternative.

N.I. Recreation is the clear winner when applying AHP, topping the results in 5 of the 9 scenarios, some of them with a comfortable advantage. The remaining 4 scenarios are topped by *Conservation* and *I. Recreation*, each one leading twice. However, these 3 alternatives are very different when we look to their worst results. While, *N.I. Recreation* never leaves the top 3 spots, *I. Recreation* occupies a medium position in some cases, sometimes more close to the top, other more close to the bottom, and *Conservation* falls to the last places in various scenarios.

Another thing that can be seen is that *Agriculture* and *Forestry* have very similar results in all scenarios excluding one or two situations. Nonetheless, *Forestry* takes the upper hand in two thirds of the scenarios relatively to *Agriculture*, leaving only one third to the latter.

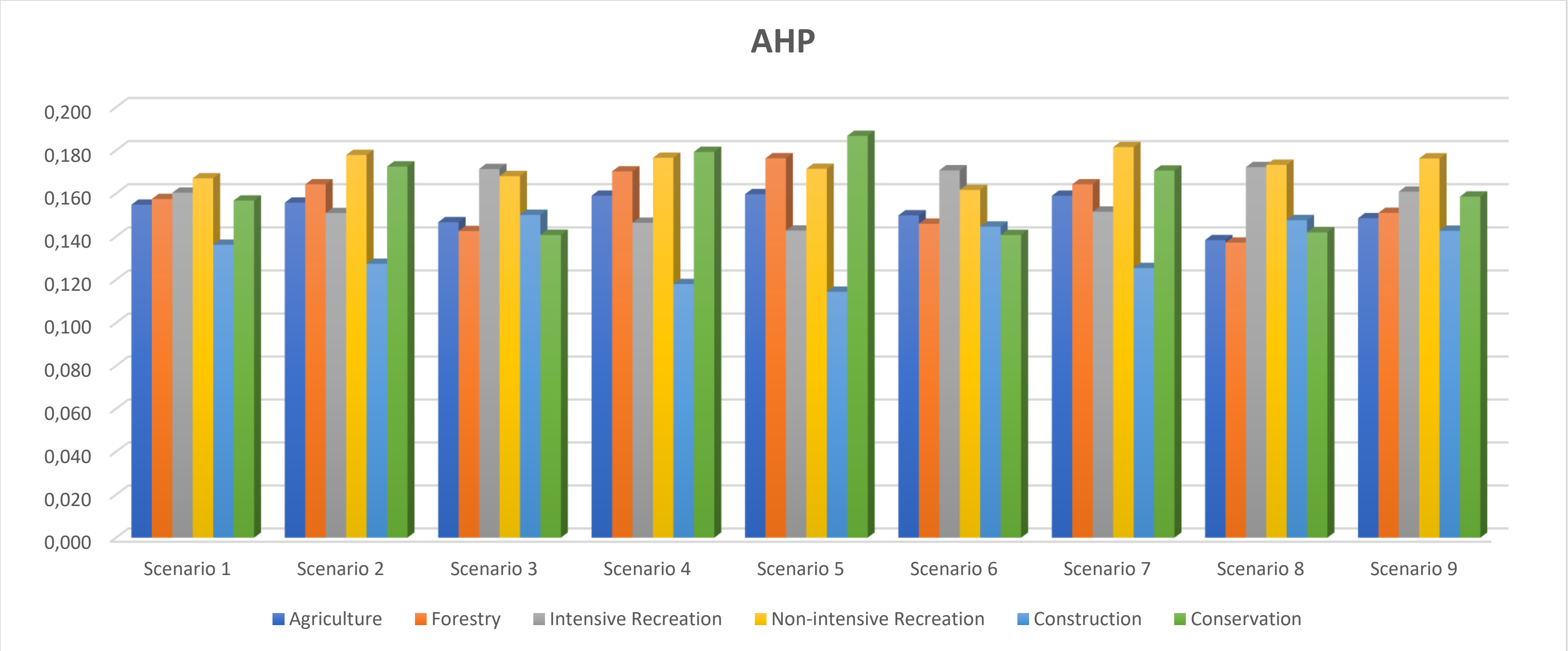


Figure 4.14 - AHP Results

4.4.3 Applying TOPSIS

Moving on to other type of MCDA methods, it will now be applied the TOPSIS technique. The main idea behind TOPSIS consists in evaluating alternatives based on the distance to the best solution (ideal) and the distance to the worst solution (anti-ideal). An alternative will have an higher score value the closest it is from the ideal point and the furthest to the anti-ideal. The results obtained using this method are showed in Figure 4.14.

Scenario 1 remains the more balanced situation, something that is expected considering the equal distribution of weights and the classification that was made. The value of the six alternatives vary very little. Unlike the full aggregation utilized previously, *Forestry* occupies the first position in a scenario. It is also worth mentioning that the similarities in values observed between Forestry and *Agriculture* in the AHP model, do not occur when using TOPSIS. When *Forestry* has higher values the distance between the two option is quite substantial, but when *Agriculture* is superior the score are very close.

Another occurrence in the TOPSIS approach is the behaviour of *Construction* bars. Although they never reaches the top spot in any Scenario, they have a bigger presence than in WSM and AHP, having a slight margin to the top spot in three scenarios, while distancing from the alternatives that scored less. In these three scenarios is always the same alternative that surpasses *Construction*, and that alternative is *I. Recreation*. This indicates that what makes *Construction* a good option in a specific scenario also makes *I. Recreation* a very reliable alternative.

The hegemony that *R.I. Recreation* has been showing is broken in TOPSIS, only toping the results in two scenarios, and in only one with a comfortable advantage. The option that takes the lead more times is *Conservation*, however it also occupies the lower positions in some scenarios, making it or a very good or a very bad alternative. The other top spots belong to *I. Recreation* (twice) and Forestry, which means that that are a total of four possible best alternatives distributed in the 9 scenarios, something that did not happen in the AHP and WSM.

As stated before, Scenario 1 shows more balance. Meanwhile, Scenarios 2, 4 and 6 reveal a bigger discrepancy, with Scenario 5 having the bigger one. The rest of the alternatives follow more or less the same tendency: an evident “separation” between the top three and the bottom three.

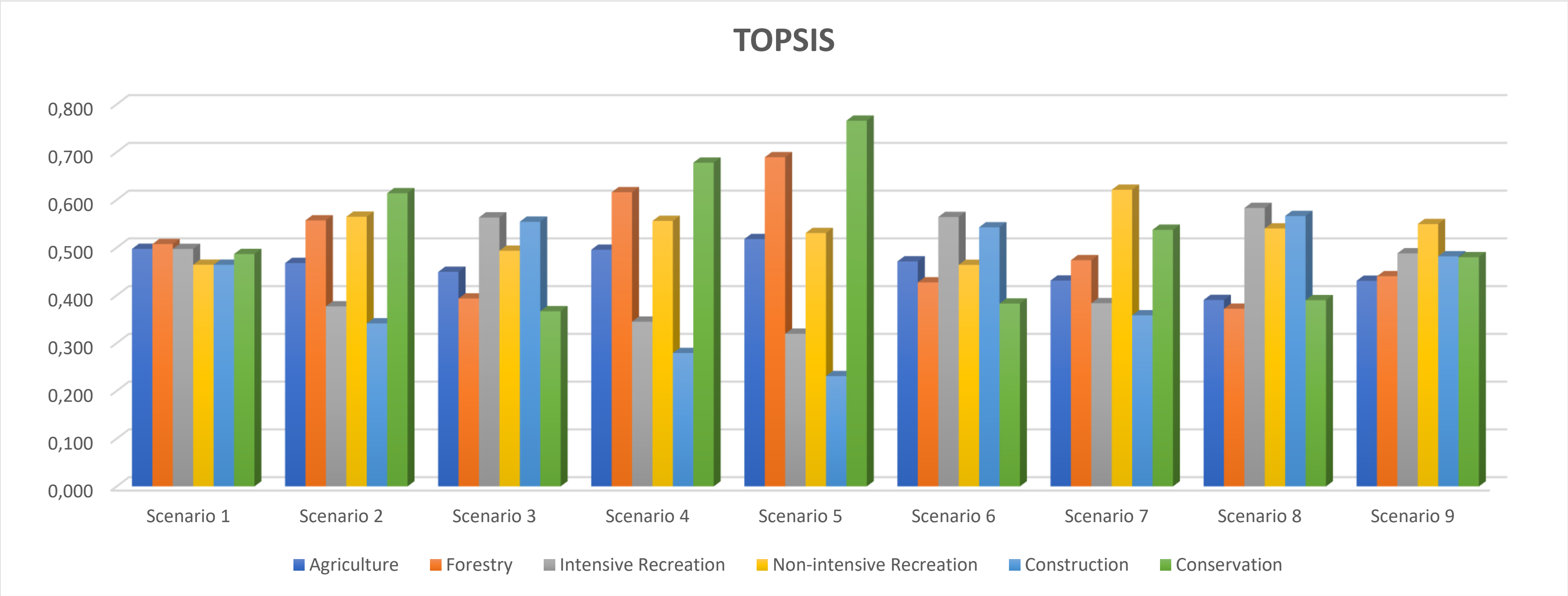


Figure 4.15 - TOPSIS Results

4.4.4 Applying VIKOR

The VIKOR method is often compared with TOPSIS, as the concept of the technique looks very similar. However, while TOPSIS focus on the distance to ideal and anti-ideal solution, VIKOR's goals is to measure the "closeness" the best solution, considering the idea of compromise. The score that is displayed in this method is the mentioned measure, so in this case the best alternative is given by the lowest values, since the closest from the ideal situation the better the alternative is, being 0 the best possible result and 1 the worst. The graphics in Figure 4.15 show the results obtained, and opposingly to the other methods, the best options will have the smaller bars instead, and not having a bar at all represents the ideal solution.

The first thing that pops out is the discrepancy between values. The concept of compromise that is considering in the VIKOR method makes the results differ a lot from the previous results that were presented.

Scenario 1 does not show balance like in AHP, WSM and TOPSIS. For the first time *Agriculture* gets the top spot, as it represents the alternative that is close to the ideal. It is followed closely by *Forestry*, and then *N.I. Recreation*, *Conservation* and *I. Recreation* appear next with little difference between themselves. Then we have *Construction* very far from the rest of the alternatives and even further from the ideal solution. This situation occurs in 5 of the 9 scenarios. The reason behind this occurrence lies in the classification of this alternative. *Construction* as a poor performance in several fields, so when the weights of the criterions where this options performs well are low, the distance to the ideal solution increases quite significatively.

Other bar that assumes a big length is the *I. Recreation*. This represents a big difference in relatively to the other methods, especially AHP and WSM, where is overall score was good.

On the other hand there are alternatives, that have no bar, which means that they have a very good score. This happens in three scenarios for *Conservation* and twice for *N.I. Recreation*. However, *Conservation* has scenarios where the distance to the ideal is very significant, while the presence of the colour yellow, that represents *N.I. Recreation* have little presence, which means that this alternative is never very far from the ideal solution.

There are interesting scenarios when using VIKOR. Starting with scenario 2, there are two alternatives that are extremely close to the ideal solution, other two that are very far and the remaining two a little closer. Scenario 3 have four alternatives with very big bars, and two with very small bars. Meanwhile, Scenario 1 is the only one without any alternative near the ideal.

VIKOR does not contemplate Scenario 9, due to the incompatibility between this technique and the Standard Deviation Method. In one of the steps of the VIKOR while using SDM, a division by 0 appears, making it impossible to calculate the final scores.

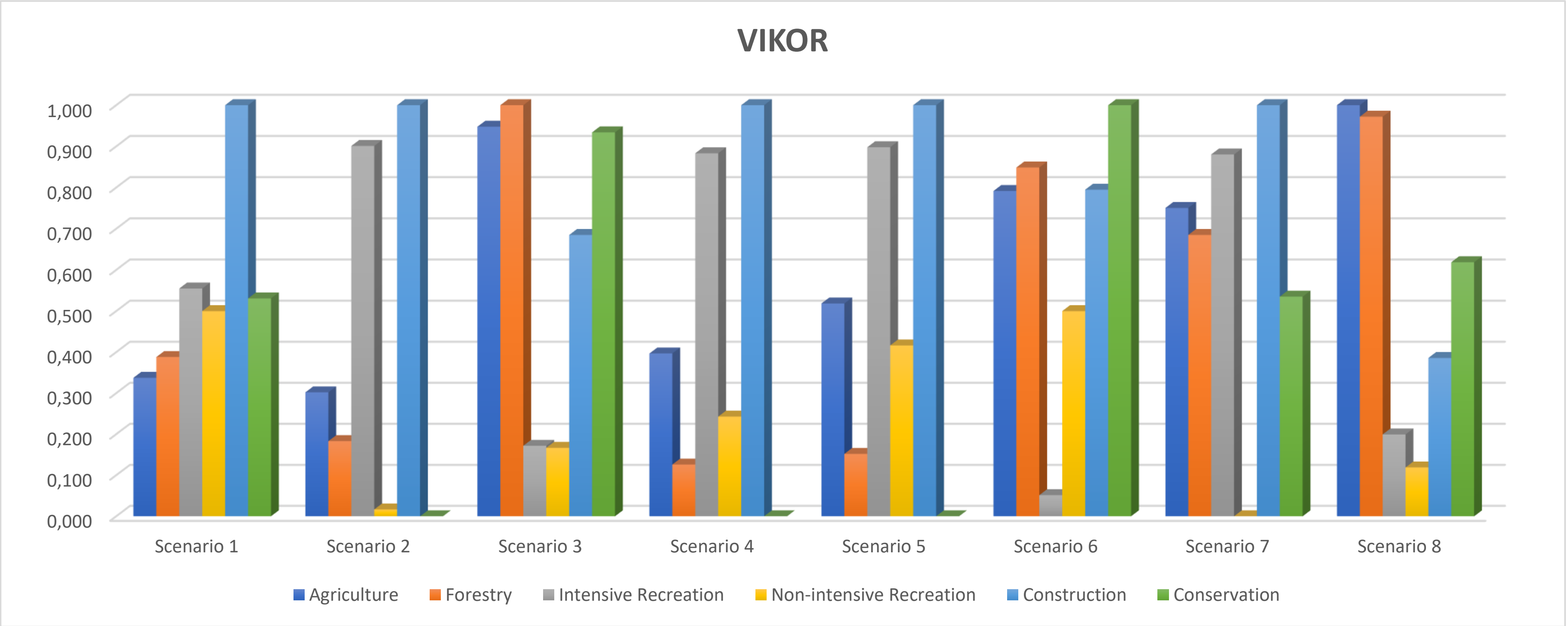


Figure 4.16 - VIKOR Results

4.5. Comparative Analysis of Results

The final step of a decision process is the recommendation that leads the stakeholders to take actions and implement a plan. This chapter purpose is to compare the various results obtained using different methods. It will be presented a compilation of results in order to allow a more general view of the all study and to take conclusions.

Table 4.18 shows the results from all methods complied. The scale of colours permits to see some patterns horizontally to compare methods, and vertically to compare scenarios. The green colour represent the best alternative and the red the worst.

The *Construction* alternative has various red cells that follow an horizontal direction meaning that is the worst alternative in several scenarios while using different methods.

On the other hand, *Conservation* and *N.I. Recreation* possess many green cells representing good alternatives a big number of times.

Following a vertical direction, which means along the same scenario and comparing each method in, a pattern shows up for every scenario. This represent consistency between different method when considering different weight scenarios. Although is not a perfect pattern, it does not get much far from that.

Now looking at Table 4.19, it is possible to verify the position each alternative assumes in in each scenario when using a certain method. With that information it was possible to calculate the average position of every alternative in each method. *N.I. Recreation* is the clear winner in that department, having the best average position in every method, with values always above 3. Meanwhile, *Construction* occupies the last position in every technique, with his best value being 4,33 and the others equal to 5.

Even though the classification was balanced between all alternatives, some evident differences are verified regarding the performances in different scenarios. This is explained by the distribution of said classification. The *N.I. Recreation* present itself as the best overall alternative because its performance is medium to good in most of criteria. Despite not having many high value, its performance does not fall down because it does not have many bad values.

Table 4.18 - Compilation of Results

		Sc1	Sc2	Sc3	Sc4	Sc5	Sc6	Sc7	Sc8	Sc9
WSM	Agriculture	3,113	3,123	2,977	3,207	3,220	3,054	3,184	2,790	2,994
	Forestry	3,217	3,342	2,908	3,483	3,608	3,005	3,335	2,801	3,079
	Intensive Recreation	3,080	2,957	3,193	2,890	2,843	3,187	2,967	3,167	3,080
	Non-intensive Recreation	3,273	3,520	3,213	3,520	3,404	3,095	3,640	3,274	3,430
	Construction	2,910	2,722	3,145	2,547	2,490	3,076	2,671	3,079	2,980
	Conservation	3,283	3,608	2,892	3,767	3,897	2,915	3,600	2,906	3,276
AHP	Agriculture	0,155	0,156	0,147	0,159	0,160	0,150	0,159	0,138	0,149
	Forestry	0,157	0,164	0,143	0,170	0,176	0,146	0,164	0,137	0,151
	Intensive Recreation	0,160	0,151	0,171	0,146	0,143	0,171	0,152	0,172	0,161
	Non-intensive Recreation	0,167	0,178	0,168	0,177	0,171	0,162	0,181	0,173	0,176
	Construction	0,136	0,127	0,150	0,118	0,114	0,145	0,125	0,148	0,143
	Conservation	0,157	0,173	0,141	0,179	0,187	0,141	0,171	0,142	0,159
TOPSIS	Agriculture	0,497	0,468	0,449	0,495	0,518	0,471	0,431	0,390	0,430
	Forestry	0,507	0,557	0,393	0,616	0,689	0,427	0,474	0,372	0,440
	Intensive Recreation	0,497	0,377	0,563	0,345	0,320	0,564	0,384	0,583	0,488
	Non-intensive Recreation	0,464	0,565	0,493	0,556	0,530	0,464	0,621	0,540	0,549
	Construction	0,464	0,341	0,554	0,279	0,231	0,542	0,358	0,566	0,482
	Conservation	0,487	0,614	0,367	0,678	0,766	0,383	0,537	0,390	0,480
VIKOR	Agriculture	0,337	0,302	0,948	0,397	0,519	0,792	0,751	1,000	undefined
	Forestry	0,388	0,183	1,000	0,126	0,152	0,849	0,685	0,972	undefined
	Intensive Recreation	0,555	0,901	0,172	0,883	0,898	0,051	0,880	0,199	undefined
	Non-intensive Recreation	0,500	0,017	0,167	0,243	0,416	0,500	0,000	0,119	undefined
	Construction	1,000	1,000	0,685	1,000	1,000	0,795	1,000	0,386	undefined
	Conservation	0,531	0,000	0,934	0,000	0,000	1,000	0,535	0,619	undefined

Table 4.19 - Comparing methods and scenarios

		Sc1	Sc2	Sc3	Sc4	Sc5	Sc6	Sc7	Sc8	Sc9	AVE.
WSM	Agriculture	4	4	4	4	4	4	4	6	5	4,33
	Forestry	3	3	5	3	2	5	3	5	4	3,67
	Intensive Recreation	5	5	2	5	5	1	5	2	3	3,67
	Non-intensive Recreation	2	2	1	2	3	2	1	1	1	1,67
	Construction	6	6	3	6	6	3	6	3	6	5,00
	Conservation	1	1	6	1	1	6	2	4	2	2,67
AHP	Agriculture	5	4	4	4	4	3	4	5	5	4,22
	Forestry	3	3	5	3	2	4	3	6	4	3,67
	Intensive Recreation	2	5	1	5	5	1	5	2	2	3,11
	Non-intensive Recreation	1	1	2	2	3	2	1	1	1	1,56
	Construction	6	6	3	6	6	5	6	3	6	5,22
	Conservation	4	2	6	1	1	6	2	4	3	3,22
TOPSIS	Agriculture	2	4	4	4	4	3	4	4	6	3,89
	Forestry	1	3	5	2	2	5	3	6	5	3,56
	Intensive Recreation	3	5	1	5	5	1	5	1	2	3,11
	Non-intensive Recreation	5	2	3	3	3	4	1	3	1	2,78
	Construction	6	6	2	6	6	2	6	2	3	4,33
	Conservation	4	1	6	1	1	6	2	5	4	3,33
VIKOR	Agriculture	1	4	5	4	4	3	4	6	undefined	3,88
	Forestry	2	3	6	2	2	5	3	5	undefined	3,50
	Intensive Recreation	5	5	2	5	5	1	5	2	undefined	3,75
	Non-intensive Recreation	3	2	1	3	3	2	1	1	undefined	2,00
	Construction	6	6	3	6	6	4	6	3	undefined	5,00
	Conservation	4	1	4	1	1	6	2	4	undefined	2,88
	More Favoured	N.I. Recreation	Consevation	I. Recreation	Conservation	Conservation	I. Recreation	N.I. Recreation	I. Recreation	N.I. Recreation	
	Less Favoured	Constructuion	Construction	Conservation	Construction	Construction	Conservation	Construction	Forestry	Agriculture	

Construction has some very good values, especially in the P.R.D. criterions, however it also has very bad values (1 and 2) in several criterions. So, the only way for this alternative be ranked higher is to attribute a very big weight to the P.R.D. criteria and a very low weight in the fields where it performs poorly.

Conservation and *I. Recreation* fight for the second best alternative while *Agriculture* and *Forestry* stay in the middle zone.

Other way to look at things is to evaluate the more and less favoured alternatives in each Scenario, when changing between methods. That evaluation shows three alternatives – N.I. Recreation, *I. Recreation* and *Conservation* - with three scenarios that favoured them the most. However *Conservation* is the less favoured in two of the Scenarios, which makes it fall behind the recreational activities, that can be considered the winners in this evaluation.

Construction, as expected, appears several times as the less favoured. *Agricultural* and *Forestry* also have a Scenario where they have the worst performance.

Looking from a global point view to all the results, it can be concluded that *N.I. Recreation* has the best overall performance and it's the most probable candidate to be implemented in this specific post-mining region (Urgeiriça). In contrast, *Construction* is the least expected option to be chosen by the stakeholder. However, it all depends on the performance matrix is built, in this study the values were the ones who have been presented but can easily be other in the eye of other decision maker, and mostly the weights that are being used. The relative importance that decision maker will attribute to each criterion according to what are the objectives and interests of the project will be the factor that will influence the results, and consequently, the final decision, the most.

5. Final Considerations

According to Piçarra et al (2021)[25], since the 1950s all through the 1670s there has been a considerable economic growth of the least developed and devolving countries nowadays. The world will certainly demand more raw materials to sustain this growth, and therefore their supply will need proper adjustments to keep the material market stable. Almeida et al (2017)[26], states that the need to achieve low weight and high strength components is insatiable. Some applications like cars and lightweight containers, for example, demand for these high performance, custom shape components, that can only be obtained from specific resources. This leads to an extensive exploration and exploitation of natural resources, especially of the mineral type. This is where the mining industry comes into scene. Its importance in the modern society and in the previous ones is unquestionable but its planning ins not always the most adequate in certain factors. Serious questions have been raised over the years. Questions mostly related with environment and sustainability. One specific problem that was raised several times is what to do after a closure of a mine, and that question remained unanswered in a large amount of times, which lead to mining regions completely abandoned without any type of concern to restore the land to its natural state and how that can affect the region and its surroundings. The EIT Project Reference 19075 "Revi-Ris: Revitalising Post-Mining Regions: Problems and Potential in RIS Europe" main objective is to tackle those situations by creating a toolkit where stakeholders can plan and apply a post-mining land use to be implemented in such regions. This tool will rely on an MCDA model to aid stakeholders and decision makers to select the best alternative for a specific mining region after its closure based on a set of conflicting criteria.

The works of this study started with the familiarization of the concepts of MDCA in order to define a framework to follow. Several methods were developed through the years and the selection of a method revealed to be the first obstacle. A comparison of the most well-known and often used methods was made so we can understand what each method could bring to the project and how the project could benefit from its application.

The next step was the definition of a set of criteria. In order to do that it was necessary to gather information about possible factors that could influence the selection of a post-mining land use. A list of several indicators from different areas was assembled and with that it was possible to create a table with five main groups of criteria: Economic, Environmental, Geoethics, Technical Issues and Potential Regional Development. Each one of those criterions are then subdivided in lower levels of sub-criteria and attributes allowing a more precise evaluation. The Economic criteria is something that was always considered, but some adjustments to present necessities were needed. The environment is a topic that has been growing substantially over the last years, representing something in the current days that is inevitable in any engineering project. Then we have Geoethics, an important field that falls into oblivion most of times. These criteria contemplate topics that are very relevant that must consider, especially when talking about mining. Safety, heritage, public opinion, culture, knowledge are all topics that Geoethics includes. These topics are more closer to the sense of Humanity in people. For this Geoethics must reach to minds of more geoscientist and people related with the geosciences. Technical Issues approaches the engineering alternatives that play a crucial role in the mining sector. The Potential Regional Development addresses the subjects related with the region and community associated with the mine. Mining regions depends essentially on mine activity. So, after its closure it is important not only to revitalize the land, but also the community.

In this perspective and considering the generated list of criteria and sub-criteria defined under ReviRIS project, application of MCDA methods considering distinct possible scenarios for final land-use and revitalization was tested in a Portuguese mine site were environmental remediation field works have already been developed: The Urgeiriça mine. Based on this mining area, six alternatives were proposed and then classified considering its characteristics and specifications. Four MCDA methods were chosen, and nine weight scenarios were defined to test different possible situations. The study showed consistency since there is a tendency in the results when looking at the bigger picture. Nevertheless, differences between methods were spotted what allowed for a better understanding of how each one operates and how it can be used. The utilised framework also allowed to compare the results in more than a way. This means that it was possible not only to compare alternatives regarding criteria, but also compare different methods against each other in distinct scenarios with variation of weights and compare different weight scenarios relatively to each method. This permitted to identify the average performance of each alternative in the various situations and which alternatives were more or less favoured in each scenario. Another important aspect that was highlighted by the results was the huge importance of weights in a MCDA model and how crucial is to define them carefully as they can completely change the outcome of the results. For this reasons, it is advisable that stakeholders always consider MCDA expertise in order to get more precise weights and improve the quality of the MCDA model to a maximum.

To conclude, it can be stated that MCDA methodology prove to be a great tool for this type of studies, due to the amount of available methods and techniques of this tool and the variability of situations to each it can be adapted. MCDA can be valuable tool in any stage of distinct types decision making processes, especially when conflicting criteria must be balanced. Post-mining rehabilitation will certainly benefits with MCDA. The ReviRIS project has all to possibilities to act as a “wind of change” regarding the mining sector, particularly in what concerns mine closure processes.

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