RESTORATION vs. REHABILITATION IN MARBLE QUARRIES. A CASE STUDY IN GREECE.

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ABSTRACT: The issue of rehabilitation of marble quarries still remains a crucial problem for the marble quarry sector of Greece. The method supported by the law (restoration of the original contour and re-vegetation of the quarry site) has proved to be ineffective mainly due to the adverse climatic conditions and the particular characteristics of marble extraction. Furthermore, when it comes to meeting the needs of local communities and improving the quality of life other approaches seem to be more suitable and effective. With a view to advocating the latter argument a comparative evaluation was conducted. Based on an operating marble quarry situated on the island of Naxos, this paper compares the typical approach with a new land-use plan by means of a Fuzzy AHP methodology. The results of the analysis demonstrate the superiority of the latter especially with regards to socio-environmental and financial aspects.

KEYWORDS : Marble quarry rehabilitation, fuzzy AHP.

RESUME: La question de la réhabilitation des carrières de marbre demeure toujours un problème crucial pour le secteur de marbre de carrière de la Grèce. La méthode soutenue par la loi (restauration de la découpe originales et de la re-végétation du site de carrière) s'est avérée inefficace principalement due aux conditions climatiques défavorables et aux caractéristiques particulières de l'extraction de marbre. En outre, quand il vient à satisfaire les besoins des communautés locales et à améliorer la qualité de la vie d'autres approches semblent être plus appropriées et efficaces. En vue de préconiser le dernier argument une évaluation comparative a été effectuée. Basé sur l'étude d'une carrière de marbre en fonctionnement située sur l'île de Naxos, cet article compare l'approche typique à un plan de nouvelle utilisation de la terre au moyen de la méthodologie de Fuzzy AHP. Les résultats de l'analyse démontrent la supériorité de ce dernier, en particulier en ce qui concerne les aspects socio-environnementaux et financiers.

MOTS-CLEFS : Réhabilitation de marbre de carrière, fuzzy AHP.

1. Introduction

The most intense problem that a marble quarry confronts does not occur during the operation but after the closure of the quarry, at the post-mining stage. The problem is related to the rehabilitation of the quarry site and it has resulted in serious conflicts between local authorities, the public and the mining companies. In a typical case the quarry would be abandoned without any attempt to restore the site or rehabilitation would mean just that a number of trees are planted. Thus, today there are over 3.000 abandoned quarries in Greece. The conflict has put at risk the marble quarry sector itself as in many cases the opening of new quarries is rejected and mining activity in general is perceived as hostile to the interests of the area.

The roots of the problem lie in two key factors: mining companies' former behaviour and legislation. In the past the mining companies have consistently considered the rehabilitation of the quarries as an issue of minor importance. Therefore, the attempts to restore the quarry sites were not carefully planned and many important parameters such as the socio-economical, cultural and historical aspects of the particular area were often neglected. Moreover, legislation has strongly supported the restoration of the abandoned marble quarries by means of backfilling and re-vegetation, a practice that has proved to be ineffective and in some cases has further aggravated the problem. Re-vegetation cannot be effectively applied in marble quarries because:

- The smooth and flat surfaces of the benches, that wire-saw cutting produces are subjected to soil erosion.
- The hard surface of the marble hinders the development of an adequate root system and the plants eventually shrivel.
- The climatic conditions deteriorate the above conditions.

It is becoming apparent by all parties involved that the term restoration does not reflect reality, nor should it be linked with re-vegetation. The very meaning of the word *restore* is wrong. After the mining activity many parameters, like the original contour of the landscape, have completely changed and it is impossible to *restore* the original conditions. Accordingly, when the surrounding area is predominately arid and vegetation is scarce, the planting of trees is bound to fail. The alternative approach that has been gaining supporters is rehabilitation. By definition rehabilitation modifies the site with a view to establishing new land-uses. When rehabilitation is applied, it takes into consideration the needs of the local community, urban planning and the characteristics of the area. Furthermore, the final plan allows for a diversity of needs to be fulfilled and can be both feasible and acceptable by all parties.

The scope of this paper is to evaluate the two different approaches with reference to a real case. The comparison is conducted on the grounds of a methodology based on the Fuzzy Analytic Hierarchy Process (Kaliampakos et al., 1999).

2. The case of Naxos

2.1. General information

The marble quarry is located on the island of Naxos, Cyclades, Greece. Administratively, the quarry is subjected to the Municipality of Naxos. It is situated at Mt. Bolibas and is a medium- sized quarry covering a total area of approximately 181.000 m^2. The quarry site is connected with the Naxos – Kinidaros main roadway via a 2,5 km secondary road.

Intense exploitation started in 1988. The exploitation is a typical open – pit quarry of ENE – WSW orientation and in its present form it consists of 12 benches ranging from level +460 to +550 m. The benches' height varies between 8 – 10 m. Benches 1 – 8 are mined out and currently production is accomplished from benches 9 (soon to be mined out) and 10 – 12. The mined out benches have a width of approximately 0,5 – 1 m and the benches have a slope angle near to vertical, thus the total slope angle reaches 75 – 80^o.

The area surrounding the quarry is mountainous and it offers a great view over the sea and a large part of the island. Contrary to other parts of the island the area around the quarry has not been considerably developed in terms of touristic infrastructure. In addition, a very important fact is that the island of Naxos has a rich historical and cultural heritage, being the place where the first ancient marble quarries operated. In fact, the area around the contemporary marble quarry was a major ancient marble extraction center.

2.2. Description of the two alternative plans

The mining company which owns the quarry assigned a research project to the Laboratory of Mining and Environmental Technology of the National Technical University of Athens. The purpose of the research project was:

- To re-design the exploitation with a view to achieving a higher degree of environmental protection.
- To suggest a rehabilitation plan for the quarry site that would strengthen the bonds between the quarrying activity and the local community.

This paper concentrates on the second part of the research project and it compares two rehabilitation plans:

- *Plan 1:* It is a typical restoration plan according to current legislation guidelines. Hence, it suggests the extensive backfilling of the quarry's benches with soil after the closure of the quarry and the re-vegetation of the site.
- *Plan 2:* It is a rehabilitation scheme that suggests the modification of an area in the quarry so as both cultural and recreational activities take place. The main element of the area is an open-air theatre constructed exclusively from non-marketable marble blocks and exploitation debris of the quarry using the layout of ancient theatres. The theatre, along with the orchestra, covers an area of 1.000 m^2 and it has a capacity of approximately 1000 seats. The theatre can host theatrical plays, concerts etc. Furthermore, the area would consist of several supplementary elements such as a wooden reception kiosk, a café and a specially modified existing bench with metal rails installation to be used by visitors to stroll. The rehabilitation plan would act as a link to the area's cultural and historical heritage connecting ancient and present quarrying activities.

Since there were few quantitative parameters available for the comparison, the Fuzzy AHP proved most useful as it takes into account both qualitative and quantitative characteristics, via the pairwise comparisons.

3. The methodology

3.1. General

The multicriteria evaluation system developed to evaluate the rehabilitation alternatives of the Naxos marble quarry utilizes the Fuzzy Hierarchical Analysis - FHA (Buckley, 1985). The method is an expansion of the popular AHP technique that was introduced by Saaty (1977, 1980) by means of fuzzy set theory (Zadeh, 1965, Bellman and Zadeh, 1970).

The AHP simplifies the analysis of complex problems due to two concepts:

(1) Decomposition of the problem into a manageable structure (hierarchy) of different levels (goal, criteria, subcriteria, alternatives)

(2) Evaluation of the elements at each level by making pairwise comparisons.

The alternatives under consideration are placed at the lowest level in the hierarchy. Pairwise assessments are made among all elements at a particular level with respect to each element in the level above it, and they can be carried out according to preference, importance, or likelihood (Table 1).

Table 1. Scale of Measurement.

Numerical Values	Definition
1	Equally important or preferred
3	Slightly more important or preferred
5	Strongly more important or preferred
7	Very strongly more important or preferred
9	Extremely more important or preferred
2,4,6,8	Intermediate values to reflect compromise
Reciprocals	Used to reflect dominance of the second alternative as compared with the first

In the case studied, Buckley's comparison matrix by means of fuzzy numbers (Nahmias, 1977, Kaufmann and Gupta, 1985) was used to calculate the comparative weights among the criteria of the hierarchy. Allowing fuzzy numbers for the pairwise comparisons proved to be useful in this particular case due to the lack of adequate quantitative data. Comparisons were accomplished using triangular fuzzy numbers, which are describe by (a/b, b/c), where $a,b,c \in Z$ and $0<a \leq b \leq c \leq 9$. The graph of the membership function μ is given Figure 1.

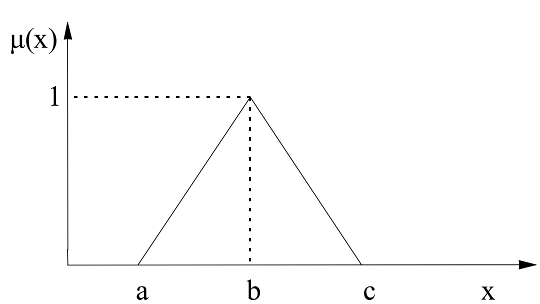

Figure 1. Membership function *μ* of the triangular fuzzy number.

The criteria weights were computed by means of the fuzzy geometric mean, as follows:

$$r_i = \left(\prod_{j=1}^{m} \overline{a_{ij}} \right)^{1/m} \tag{1}$$

where $\overline{a_{ij}}$ = (a_{ij}/b_{ij}, b_{ij}/c_{ij}) are fuzzy triangular numbers for *m* assessment criteria (evaluators), denoting the preference of criterion *i* against criterion *j*.

The fuzzy weights $\overline{w_i}$ for *m* evaluators are then computed by the equation:

$$\overline{w_i} = r_i/(r_1+\ldots+r_m) \tag{2}$$

By substituting $\overline{a_{ij}}$ = (a_{ij}/b_{ij}, b_{ij}/c_{ij}) in Eqs. (1) and (2) it concludes that fuzzy weights $\overline{w_i}$ are determined by:

$$(\alpha_i\gamma^{-1}/\beta_i\beta^{-1},\ \beta_i\beta^{-1}/\gamma_i\alpha^{-1}) \tag{3}$$

Given that the graph of the membership function μ_i (Figure 2) of these numbers equals to 0 to the left of $\alpha_i\gamma^{-1}$, x=f_i(y)/g(y) on the interval [$\alpha_i\gamma^{-1}$,$\beta_i\beta^{-1}$], x=g_i(y)/f(y) on the interval [$\beta_i\beta^{-1}$,$\gamma_i\alpha^{-1}$] and zero to the right of $\gamma_i\alpha^{-1}$, then:

$$a_i = \left[\prod_{j=1}^{m} \mathrm{a}_{ij} \right]^{1/m} \text{ and } a = \sum_{i=1}^{m} a_i \text{, similarly } \beta_i, \beta, \gamma_i, \gamma \text{ are defined} \tag{4}$$

$$f_i(y) = \left[\prod \left((\mathrm{b}_{ij} - \mathrm{a}_{ij})y + \mathrm{a}_{ij} \right) \right]^{1/m} \tag{5}$$

$$g_i(y) = \left[\prod \left((\mathrm{b}_{ij} - \mathrm{c}_{ij})y + \mathrm{c}_{ij} \right) \right]^{1/m} \tag{6}$$

$$f(y) = \sum_{i=1}^{m} f_i(y) \tag{7}$$

$$g(y) = \sum_{i=1}^{m} g_i(y) \tag{8}$$

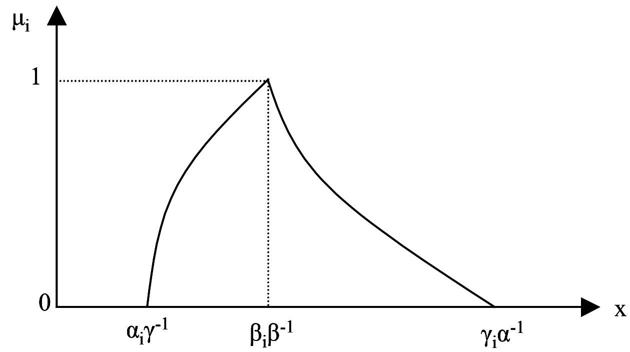

Figure 2. Membership function μ_i of the fuzzy weight $(\alpha_i\gamma^{-1}/\beta_i\beta^{-1}, \beta_i\beta^{-1}/\gamma_i\alpha^{-1})$ for the criterion *i*.

In order to introduce the fuzzy weights into the aggregation function, the expected values $E_{[\mu(x)]}$, which are crisp numbers, should be calculated, as follows (Li and Liu, 1990):

$$w_m = E_{[\mu_A(x)]} = \frac{\int x * \mu_A(x)dx}{\int \mu_A(x)dx} \tag{9}$$

where w_m is the crisp weight of criterion *m* and $\mu(x)$ is the membership function of the corresponding fuzzy weight.

The equation is solved by applying the trapezoidal rule under the following assumptions: by definition of Eqs. (5) and (6), it comes that $\forall\ x_{i,j}$: i,j = 1,2,... with $\mu(x_i)=\mu(x_j)=y$, it is μ(x)=y, where $x=x_i x_j$. Given that $x=f_i(y)/g(y)$ and $x=g_i(y)/f(y)$ for both legs of the membership function, and since y varies between 0 and 1, Eq. (9) can be solved numerically using successive intervals of y.

Finally, given the crisp weights of the pairwise comparisons of the alternatives according to each criterion, an overall index is computed in order to rank the alternatives, as presented in the next section.

3.2. Implementation of the methodology

The implementation of the methodology includes four steps:

- Objectives: definition of the problem and the objectives
- Criteria: description of the main parameters interfering with the problem
- Weighting of the criteria
- Evaluation and ranking: use of the criteria and weights to meet the objectives

In the case presented in this paper the problem was to evaluate the two rehabilitation plans in terms of feasibility and approval from the public's side. Each step of the methodology is described below. It is stressed that due to insufficient knowledge regarding the groups involved in the decision process (providers of the facilities, financial supporters, local authorities etc.) that particular level of the hierarchy was omitted (Figure 3).

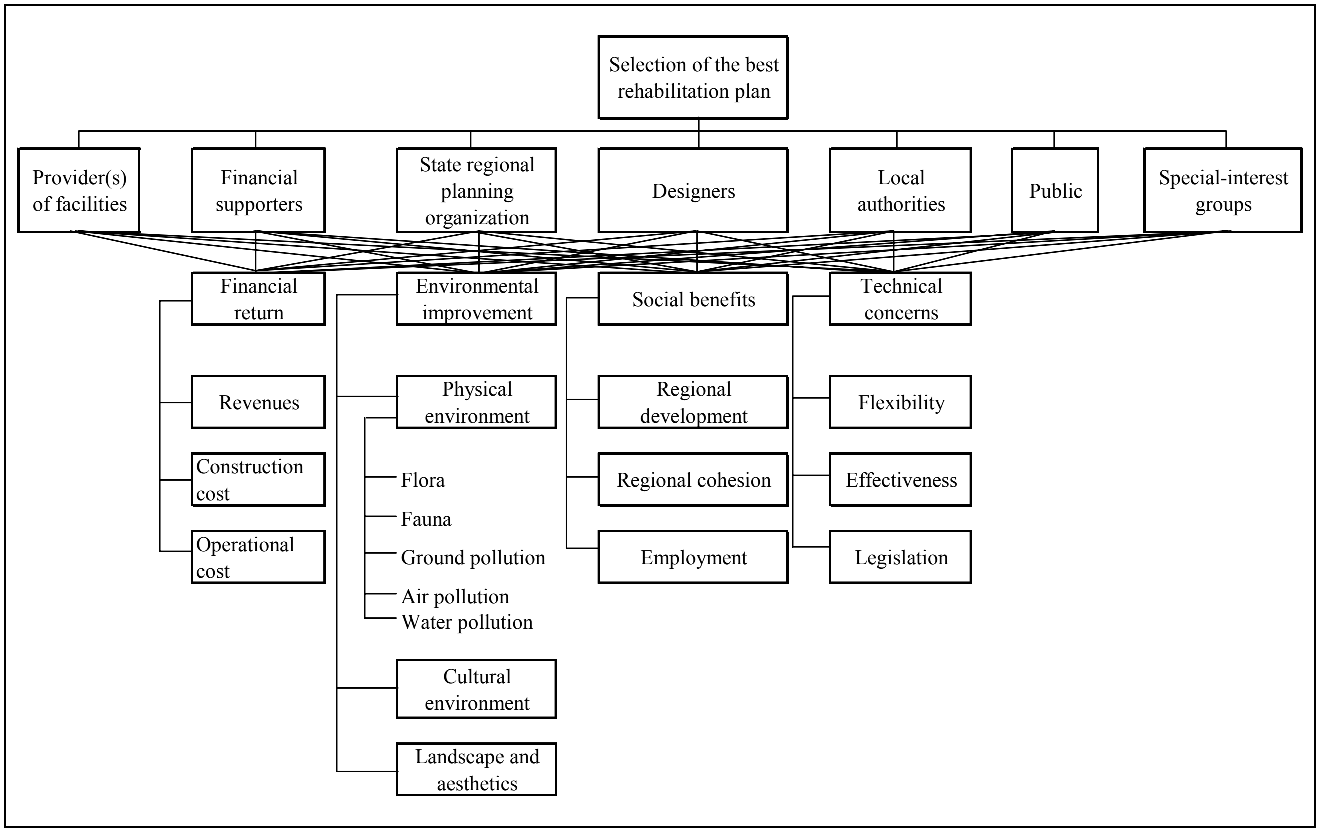

Figure 3. Structure incorporating hierarchy of criteria.

a. Objectives

The primary objectives for the evaluation of the two rehabilitation plans were:

- Financial return (F)
- Environmental improvement (E)
- Social benefits (S)
- Technical concerns (T)

The scenario that was used to evaluate the two plans aims at the maximization of the socio-environmental benefits deriving from each approach. Thus, the priorities were:

- F = 0,25, E = 0,30, S = 0,30, T = 0,15

b. Criteria

At a second level the evaluation criteria are defined. Each of the four objectives comprises a set of criteria that are used to assess the performance of the two rehabilitation plans. Financial return includes three criteria, revenues (F1), construction cost (F2) and maintenance cost (F3). The environmental objective consists of three criteria: the physical environment (E1), the cultural environment (E2) and landscape and aesthetics (E3). Social benefits are also described by three criteria: regional development (S1), regional cohesion (S2) and employment (S3). Finally, technical concerns include three criteria: flexibility (T1), effectiveness (T2) and conformity with the law (T3).

3.3. Weighting

The establishment of the hierarchy provided twelve criteria, that where used to develop the fuzzy weights for each objective, by means of the FHA:

Table 2. Financial return criteria weights.

	F1	F2	F3
F1	1/1,1/1	3/4,4/5	4/5,5/6
F2	0.2/0.25,0.25/0.33	1/1,1/1	3/4,4/5
F3	0.17/0.2,0.2/0.25	0.2/0.25,0.25/0.33	1/1,1/1

Table3. Environmental improvement criteria weights.

	E1	E2	E3
E1	1/1,1/1	0.2/0.25,0.25/0.33	0.25/0.33,0.33/0.5
E2	3/4,4/5	1/1,1/1	2/3,3/4
E3	2/3,3/4	0.2/0.25,0.25/0.33	1/1,1/1

Table 4. Social benefits criteria weights.

	S1	S2	S3
S1	1/1,1/1	1/1,1/1	1/1,1/1
S2	1/1,1/1	1/1,1/1	1/1,1/1
S3	1/1,1/1	1/1,1/1	1/1,1/1

Table 5. Technical concerns criteria weights.

	T1	T2	T3
T1	1/1,1/1	2/3,3/4	4/5,5/6
T2	0.25/0.33,0.33/0.5	1/1,1/1	3/4,4/5
T3	0.17/0.2,0.2/0.25	0.2/0.25,0.25/0.33	1/1,1/1

The following process was to determine the fuzzy performance matrices of the alternative plans (P1, P2) with respect to each evaluation criterion:

Table 6. Pairwise comparison for the assessment criterion F1.

	P1	P2
P1	1/1,1/1	0.17/0.2,0.2/0.25
P2	4/5,5/6	1/1,1/1

Table 7. Pairwise comparison for the assessment criterion F2.

	P1	P2
P1	1/1,1/1	6/7,7/8
P2	0.13/0.14,0.14/0.17	1/1,1/1

Table 8. Pairwise comparison for the assessment criterion F3.

	P1	P2
P1	1/1,1/1	5/6,6/7
P2	0.13/0.17,0.17/0.2	1/1,1/1

Table 9. Pairwise comparison for the assessment criterion E1.

	P1	P2
P1	1/1,1/1	2/3,3/4
P2	0.25/0.33,0.33/0.5	1/1,1/1

Table 10. Pairwise comparison for the assessment criterion E2.

	P1	P2
P1	1/1,1/1	0.13/0.14,0.14/0.17
P2	6/7,7/8	1/1,1/1

Table 11. Pairwise comparison for the assessment criterion E3.

	P1	P2
P1	1/1,1/1	0.25/0.33,0.33/0.5
P2	2/3,3/4	1/1,1/1

Table 12. Pairwise comparison for the assessment criterion S1.

	P1	P2
P1	1/1,1/1	0.13/0.14,0.14/0.17
P2	6/7,7/8	1/1,1/1

Table 13. Pairwise comparison for the assessment criterion S2.

	P1	P2
P1	1/1,1/1	0.13/0.14,0.14/0.17
P2	6/7,7/8	1/1,1/1

Table 14. Pairwise comparison for the assessment criterion S3.

	P1	P2
P1	1/1,1/1	0.17/0.2,0.2/0.25
P2	4/5,5/6	1/1,1/1

Table 15. Pairwise comparison for the assessment criterion T1.

	P1	P2
P1	1/1,1/1	0.14/0.17,0.17/0.2
P2	5/6,6/7	1/1,1/1

Table 16. Pairwise comparison for the assessment criterion T2.

	P1	P2
P1	1/1,1/1	0.11/0.13,0.13/0.14
P2	7/8,8/9	1/1,1/1

Table 17. Pairwise comparison for the assessment criterion T3.

	P1	P2
P1	1/1,1/1	4/5,5/6
P2	0.17/0.2,0.2/0.25	1/1,1/1

3.4. Evaluation and ranking

The determination of the fuzzy preferences for each criterion and each alternative is followed by the de-fuzzification procedure to compute non-fuzzy values that adequately represent the membership function. This particular stage includes a large volume of calculations and for the sake of simplicity it is omitted. In the following Tables, the non-fuzzy criteria weights for each objective (Table 18) and the non-fuzzy alternative weights for each criterion (Table 19) are given respectively.

Table 18. Criteria weights for each objective.

	Financial	**Environmental**	**Social**	**Technical**
F1	0,683			
F2	0,255			
F3	0,095			
E1		0,128		
E2		0,643		
E3		0,289		
S1			0,333	
S2			0,333	
S3			0,333	
T1				0,649
T2				0,298
T3				0,099

Table 19. Pairwise comparisons of the plans.

	Plan 1	**Plan 2**
F1	0,171	0,842
F2	0,879	0,127
F3	0,866	0,144
E1	0,773	0,268
E2	0,127	0,879
E3	0,268	0,773
S1	0,127	0,879
S2	0,127	0,879
S3	0,171	0,842
T1	0,145	0,864

T2	0,112	0,893
T3	0,842	0,171

Finally the total weight of each alternative is calculated using the objective weights (scenario), the criteria weights and the scores of the alternatives by means of the following equation:

$$W_{ik} = C_k * \sum_{j=1}^{3} c_j w_{ij}^c + E_k * \sum_{j=1}^{3} e_j w_{ij}^e + S_k * \sum_{j=1}^{2} s_j w_{ij}^s + T_k * \sum_{j=1}^{3} t_j w_{ij}^t \qquad (10)$$

where W_{ik} = the overall weight of alternative *i* for the scenario *k,* C_k, E_k, S_k, T_k = the priority of the objectives, corresponding to the scenario *k,* c_j, e_j, s_j, t_j = the criteria weights for each objective (Table 18), w_{ij} = the score of the alternative for each criterion (Table 20).

The final ranking of the two alternatives is given in the following table:

Table 20. Final ranking of the alternatives.

	Socio-Environmental scenario
Plan 1	0,246
Plan 2	0,754

4. Conclusions

In general, selecting between different plans and land-uses for marble quarry rehabilitation is a complicated and difficult task. Often there is a diversity of contradictory factors that affect the problem. The decision process involves many groups that usually have vested interest, fact that makes the decision process even more difficult.

In the case presented in this paper the aim was to evaluate two different proposals with the priority of achieving maximum socio-environmental benefits for the surrounding area. The evaluation was carried out on the grounds of the Fuzzy AHP.

The outcome of the analysis advocates that the best plan for the selected scenario is the establishment of new land-uses (Plan 2). Despite the fact that the proposed scheme does not fully follow the current legislation's guidelines, the relatively high scores achieved in the social and environmental objectives ensure that it outweighs the restoration and re-vegetation plan. The scheme takes into account several characteristics of the surrounding area such as the needs of the local community, the historical and cultural background of the area as well as the particular features of the marble quarry. Therefore, the proposed scheme is an integrated and feasible solution for the rehabilitation of the marble quarry. Nevertheless, the analysis should be revised as soon as the priorities of the groups involved in the decision process become available as their preferences are of vital importance.

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