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Dealing with a multiple criteria environmental problem with interaction effects between criteria through an extension of the ELECTRE III method

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ABSTRACT

In this article we compare five alternative projects for the requalification of an abandoned quarry. The starting point for this paper was a request made by a decision maker. It was not for help in making a decision as such, but rather for a comparison of different projects. In particular, we are interested in ranking the considered projects on the basis of six different criteria. An extension of the ELECTRE III method with interactions between pairs of criteria was applied in the research. A focus group of experts (in economic evaluation, environmental engineering, and landscape ecology) was formed to be in charge of the process leading to the assignment of numerical values to the weights and interaction coefficients. We report on the way the process evolved and on the difficulties we encountered in obtaining consensual sets of values. Taking into account these difficulties, we considered other sets of weights and interaction coefficients. Our aim was also to study the impact on the final ranking of the fact that these numerical values, assigned to the parameters, were not perfectly defined. This allowed us to formulate robust conclusions which were presented to the members of the focus group.

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1. Introduction

The starting point of the work presented in this article comes from a request made by a decision maker. It was not for help in making a decision as such, but rather for a comparison of five requalification actions or projects for an abandoned quarry. In addressing the problem for study, the comparison has to take into account several stakeholders' different points of view. To do so, an adequate and coherent family of criteria has to be built. The authors of the current study had good reasons to think that in a context of sustainability assessment they should not discard *a priori* the possibility of interactions between some pairs of criteria. Indeed, in the context of sustainability assessment, economic sustainability has an ecological cost and ecological sustainability has an economic cost (Munda, 2005). Following this reasoning, it is possible to state that in the particular context of sustainability assessment the different aspects (required for the construction of criteria) usually interact with each other, reflecting the natural dynamics of environmental and land-use territorial systems. Consequently, it seemed justified to try to highlight potential synergies, redundancies, or other phenomena among coalitions of criteria.

Given the possible existence of interaction between some pairs of criteria, we undertook a detailed overview of the main approaches used in the literature to consider the evaluation of interaction effects. This analysis led to the choice of an extension of ELECTRE III with interactions (Figueira, Greco, & Roy, 2009), which has proved to be an appropriate method (*cf.* Section 2, below). The comparison of five alternative requalification projects for an abandoned quarry (*cf.* Section 3) seemed to the authors a very good opportunity to test this extension of ELECTRE III. Of particular interest was the question of whether with this method it was possible to highlight and build robust conclusions, taking into account the existence of some arbitrariness when assigning values to the main parameters (weights of criteria and interaction coefficients). To assign numerical values to these parameters and to implement the method in general, it was necessary to form a focus group (*cf.* Section 3). Section 4 reports the way the focus group worked. Section 5 provides the results of the application and discusses the findings through a sensitivity analysis, which enabled us to highlight and build robust conclusions. Finally, Section 6 contains the main conclusions that can be drawn from the research.

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2. Adopting an MCDA method to handle interaction between criteria

When the analyst was confronted with this case study, he had good reasons to believe that he should take into account the interactions between criteria (this was later confirmed, see Section 3). Under these conditions, the choice of a multiple criteria approach was examined. Thus, the multiple criteria methods taking into account interaction between criteria were reviewed to adopt a suitable one.

There is currently a great variety of multiple criteria decision aiding (MCDA) methods and this means that the task of adopting the appropriate method for a certain decision-aiding situation is not an easy one (see Roy & Słowiński, 2013). There are also a certain number of methods considering the interaction between criteria. It should be noted that there is no interaction between criteria in the case of preference independence (see, *e.g.*, Keeney and Raiffa, 1976). The possible weakening of preference independence, implying some form of interaction between criteria, has been under discussion for some time (see, *e.g.*, Fishburn and Keeney, 1975; Keeney, 1981). Probably the most well-known method emerging from this literature is the multilinear utility functions (Keeney & Raiffa, 1976). This method aggregates values of the considered criteria through a weighted-sum of products of the marginal utilities corresponding to the single criterion over all the subsets of criteria. The limitations of this aggregation procedure are the difficulty in defining the many, and to some extent heterogeneous, weights (one for each subset of criteria) and the marginal utility functions themselves. Another methodology to deal with interaction among and between criteria considers non-additive integrals, such as the Choquet integral (Choquet, 1953; Grabisch, 1996) and the Sugeno integral (Sugeno, 1974) and their generalization, such as the bipolar Choquet integral (Grabisch & Labreuche, 2005) or the level dependent Choquet integral (Greco, Matarazzo, & Giove, 2011). The basic idea of this approach is that the interaction between criteria can be modeled through the non-additive importance of criteria represented by the value assigned to each subset of criteria by a capacity, called also a fuzzy measure. This is valid at least in the basic version of the Choquet integral and Sugeno integral. This approach has several drawbacks (see Roy, 2009), the most important of which is that they require evaluations on criteria expressed on the same scale (for a proposal to determine the common scale that is necessary in order to apply the Choquet integral, see Angilella, Corrente, and Greco, 2015). Recently, the interaction between criteria through a weakening of the preference independence condition has been given some consideration in the domain of Artificial Intelligence through GAI-networks (Gonzales & Perny, 2004), as well as UCP-networks (Boutilier, Bacchus, & Brafman, 2001), which are based on the idea of Generalized Additive Independence (GAI) decomposition introduced by Fishburn (1970). They allow for aggregating performances on the considered criteria through the sum of marginal utilities related to subsets of criteria. The main problem with these methods is the difficulty in eliciting the marginal utilities from preference information given by the decision maker. Another approach, recently proposed to deal with the interaction of criteria, is the use of enriched additive value functions. Besides the usual sum of marginal utility functions related to each of the considered criteria, these have some further terms representing interaction between a small number of couples of criteria in terms of bonus, in case of synergy between criteria, or penalization, in case of redundancy between criteria (Greco, Mousseau, & Słowiński, 2014). Since the decision maker could have some difficulties in defining for which couples there is synergy or redundancy, the couples of interacting criteria are singled out with an ordinal regression approach on the basis of some preference information expressed by the decision-maker in terms of pairwise preference comparison of alternatives. Another possibility, recently proposed in the literature (Corrente, Figueira, & Greco, 2014), is to apply a Choquet-like aggregation method in aggregation of the preference functions outranking methods apart from Electre methods, such as the Promethee methods.

Taking into account all the above aggregation procedures, the choice of an extension of Electre III taking into account interactions between criteria (Figueira et al., 2009) was judged to be completely adequate for dealing with the case study presented in the next section, for the following reasons:

(i) Electre methods allow for dealing with heterogeneous scales. In the present study the performances of the actions were expressed on ordinal scales for four criteria, while for the other two criteria the scales were quantitative.
(ii) Electre methods are able to take into account purely ordinal scales, thus maintaining their original concrete verbal meaning. In other words, there is no need to convert the original scales into abstract ones with an arbitrary imposed unit and range.
(iii) Electre methods also allow for taking into account indifference and preference thresholds when modeling imperfect knowledge of data. In our study it was necessary to take imperfect knowledge into account; for such a purpose the definition of indifference and preference thresholds seemed perfectly adequate.
(iv) The generalization of Electre methods allows for consideration of the interaction between some couples of criteria, which seemed to be present in our study. In addition, it was considered to be the right opportunity for testing the applicability of Electre III with interactions.

3. Case study: the requalification of an abandoned quarry

This study deals with the characterization and comparison of alternative projects for the requalification of an abandoned quarry located in Northern Italy. In particular, this study concerns the analysis and the comparison of five projects in order to rank them from the best to the worst one. Details about the case study are provided in what follows.

3.1. A brief description of the context

The application performed in the present research is based on the results coming from a previous study where the alternative options have been identified and investigated (Bottero, Ferretti, & Pomarico, 2014; Brunetti, 2007). The area under analysis refers to a quarry that has been abandoned since 1975 and covers a total surface of 65,000 square meters, with a depth of approximately 25 meters from the ground level. Due to its abandoned state the area is now characterized by uncontrolled vegetation growth and by water-filled pits. Furthermore, the area under analysis is part of the Provincial ecological system of environmentally valuable sites.

For the reclamation of the area five alternative projects have been considered, that can be described as follows: (1) basic reclamation, (2) to plant a forest, (3) development of a wetland, (4) implementation of the ecological network, and (5) construction of a recreational structure. It is worth mentioning that the projects represent real projects, which are now under investigation from the Municipal Authority for the transformation of the area. The five alternative options that were proposed for the requalification of the abandoned quarry can be described in a more detailed form as follows:

1. *Basic reclamation*: This alternative involves the filling of the quarry, the implementation of security measures on the quarry's slope characterized by landslide risk, the laying of the topsoil, the natural evolution of the vegetation, and the accelerated growth of the autochthonous black locust wood.
2. *Valuable forest*: This alternative involves the filling of the quarry, the implementation of security measures on the quarry's slope characterized by landslide risk, the laying of the topsoil, the

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