Original Article

The use of multi-criteria analysis in the recovery of abandoned mines: a study of intervention in Portugal

A utilização de análise multicritério na recuperação de minas abandonadas: estudo da intervenção em Portugal

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Abstract

Considering that the budget for the recovery of abandoned mining zones is limited, it was necessary to develop a model that would make it possible to choose which mines should be targeted for intervention, taking into account the various factors by which their external effects may be assessed (the environment, public health, the landscape and their usefulness to industrial archaeology). A multi-criteria analysis using the analytic hierarchy process, in which each major factor, result, and mine are compared, was employed to generate an innovative assessment model that guaranteed that the overall value of the intervention was maximised, compared to two other methods (intervention ranked by the greatest overall severity and ranked by the cost–benefit ratio). The results indicate an economically and socially viable and efficient choice, making it possible to undertake new similar studies.
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Keywords: Brownfields; Multi-criteria analysis; Analytic hierarchy process (AHP); Capital rationing decision

Resumo

Tendo em consideração a existência de uma limitação orçamentária que inviabilizava a recuperação de todas as áreas mineiras abandonadas, foi necessário desenvolver um modelo que permitisse escolher quais as minas que seriam objeto de intervenção, tendo em consideração os diferentes fatores de avaliação de seus efeitos externos (no ambiente, na saúde pública, na paisagem e no seu aproveitamento para a arqueologia industrial). A partir de uma análise multicritério (utilizando o *Analytical Hierarchy Process* - AHP), onde cada fator preponderante, resultado e mina foram comparados, gerou-se um modelo inovador de avaliação onde se garantiu a maximização do valor global da intervenção, em comparação a outros dois métodos (intervenção ordenada pela maior gravidade global e pela relação custo-benefício). Os resultados apontam para uma escolha econômica e socialmente viável e eficiente, permitindo instigar novos estudos análogos.
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Palavras-chave: Minas abandonadas (brownfields); Análise multicritério; *Analytical Hierarchy Process* (AHP); Decisões com restrição orçamentária

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Introduction

The recovery of abandoned mines is essential from a social perspective, given their visibly negative effects, predominantly due to the water pollution, soil contamination, and inadequately protected landfills associated with these mines (Abreu, Matias, Magellan, & Basto, 2008; Antunes & Albuquerque, 2013; Cesar, Egler, Polivanov, Castilhos, & Rodrigues, 2011, Mayan, Silva, & Begonha, 2006; Neves & Matias, 2008; Veiga & Hinton, 2002). The complexity of the effects, which include multiple dimensions, has been the object of several scientific developments, particularly multi-criteria analysis (Huang, Keisler, & Linkov, 2011; Pizzol et al., 2016; Wedding & Crawford-Brown, 2007).

What criteria should guide the choice of which mines to recover? How should the investment in mine recovery be allocated, considering budgetary restrictions? The present article seeks to present an innovative approach to selecting which mines should be recovered based on a study conducted in Portugal. Given the high number of abandoned mines in that country and the limited budget for their recovery, it was necessary to identify priority mines, considering the set of harmful effects to be mitigated and the cost of each project.

The theoretical justification for this study is that it addresses a problem of project selection in a context of capital rationing (Weingartner, 1963, 1977), raising the issue of the various harmful effects identified, to find a single indicator of "value" for each mine (defined, in this case, as the amount of harm to be eliminated). Given that some of the harmful effects are difficult to quantify, it was necessary to use an analysis that compares the mines being studied and, in this manner, creates an index for each mine. To that end, a multi-criteria analysis model was applied.

The hierarchy model chosen was the analytic hierarchy process (AHP), developed by Saaty (1980, 1986), which, in a multi-criteria and hierarchical structure, enables the endogenous generation of weights that reflect the value associated with recovery so that these are not assigned arbitrarily; simultaneously, it tests the consistency of the values assigned by evaluators. These weights were then used as coefficients of the objective function to be maximised in the model for selecting projects in a context of capital rationing.

This paper also aims to contribute to a broad understanding of the model by which abandoned mines are analysed and selected for recovery, using a socioeconomic perspective that may be applied to other similar interventions.

In addition to this introduction, which presents the problem, objective, and justifications, this study has five other sections. The second addresses the theoretical framework. The third describes the research environment surrounding the study's problem and motivations. The fourth addresses the methodology used to develop the proposed model, and the fifth contains the findings and discussions arising from the research conducted. Finally, the sixth chapter covers the conclusions, followed by the references.

Multi-criteria analysis

The initial studies on choice or selection analysis took into account only one objective function. The perception that a single function was insufficient to simulate real-world situations led operational research to study multiple conditions and selection criteria. This led to the need to use multi-criteria analysis, which may be viewed as a method of allowing the manager to make choices in situations of ambiguity, bifurcations, and uncertainties (Roy & Bouyssou, 1991).

According to Parreiras (2006), there are two schools of multi-criteria analysis: an American school and a French or European school. The American school methods focus the decision on the construction of a utility function, whereas the French school treats the decision as a two-stage process, in which the first stage consists of comparison and the second stage explores relations according to guidelines or classifications. In other words, the first school can be classified as normative and the second as constructivist, in that it helps the manager construct his or her preferences (Parreiras, 2006). Some authors thus differentiate between the American school methods, as multiple criteria decision making (MCDM), and the French School methods, as multi-criteria decision aid (MCDA) (Parreiras, 2006; Roy, 1990; Vincke, 1986), although other authors make no distinction between these two frameworks.

One of the most well-known and frequently used methods of multi-criteria analysis (Wallenius et al., 2008) is the AHP method developed by Saaty (1980, 1986), which structures the decision process by identifying an overall objective, criteria, and alternatives. It is a versatile method that has had various applications, including the allocation of energy for industries, transportation planning, the process of evaluating candidates for election, and the choice of priorities for promoting teachers and researchers, among others (eg. Horn, 1997; Huang et al., 2008; Liberatore and Nydick, 2008; Sipahi and Timor, 2010; Wong and Li, 2008; Zavadskas et al., 2014). Its theoretical features and robust applicability justify its choice for the analysis of mines to be recovered in Portugal.

The AHP is based on three basic principles (Saaty, 1986, 2000), which constitute the three stages of the process:

1. The principle of decomposition consists of breaking down complex problems into less complex "sub-problems" so that humans, with their cognitive constraints, are better able to analyse and decide upon them. Hierarchical decomposition is even considered by Simon (1960) to be the best method for humans to address complexity; therefore, the first step of the AHP is to precisely break down the problem into a hierarchical decision model, including criteria, sub-criteria, and alternatives.
2. The principle of comparative judgement holds that humans are capable of drawing comparisons only within a limited spectrum of alternatives, as demonstrated by various experiments and studies on brain functioning. Hence, instead of