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Choosing among weight-estimation methods for multi-criterion analysis: A case study for the design of multi-purpose offshore platforms

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ABSTRACT

Application of the sustainability concept to environmental projects implies that at least three feature categories (i.e., economic, social, and environmental) must be taken into account by applying a participative multi-criterion analysis (MCA). However, MCA results depend crucially on the methodology applied to estimate the relative criterion weights. By using a logically consistent set of data and methods (i.e., linear regression [LR], factor analysis [FA], the revised Simos procedure [RSP], and the analytical hierarchy process [AHP]), the present study revealed that mistakes from using one weight-estimation method rather than an alternative are non-significant in terms of satisfaction of specified acceptable standards (i.e., a risk of up to 1% of erroneously rejecting an option), but significant for comparisons between options (i.e., a risk of up to 11% of choosing a worse option by rejecting a better option). In particular, the risks of these mistakes are larger if both differences in statistical or computational algorithms and in data sets are involved (e.g., LR vs. AHP). In addition, the present study revealed that the choice of weight-estimation methods should depend on the estimated and normalised score differences for the economic, social, and environmental features. However, on average, some *pairs* of weight-estimation methods are more similar (e.g., AHP vs. RSP and LR vs. AHP are the most and the least similar, respectively), and some *single* weight-estimation methods are more reliable (i.e., FA > RSP > AHP > LR).

1. Introduction

Application of the sustainability concept to environmental management, in general, and environmental projects, in particular, implies that at least three feature categories (i.e., economic, social, and environmental) must be taken into account (e.g., for environmental projects, see [1–5]). In this paper, I will refer to the MERMAID multi-purpose offshore platform project (www.mermaidproject.eu) as an instance of development of offshore multi-use platforms (i.e., a possible combination of fish, wind and wave farms), that requires a comparison of alternative designs (e.g., for environmental designs, see [6–10]). However, each design option has different features that must be evaluated using dedicated indicators. Thus, as a starting point, the literature on the selection among alternatives will be considered to provide context for this analysis.

To simplify the theoretical analysis, let us assume that time is not relevant, so that the sequence of project implementation or the movement of resources from t to $t+1$ can be disregarded [11]. Moreover, let us assume that there are no interdependencies between projects [12], neither through a monetary budget nor through spatial linkages. Finally, let us assume that there is no risk from the projects, so that the attitudes of decision-makers towards risk are irrelevant [13]. In other words, the problem consists of providing a list of n non-dominated designs. *Alternatively*, it is possible to search for an ordered list of n options [14]. However, the sustainability criterion that has become an increasingly important factor in modern project planning suggests that projects are characterised by a range of features that can be grouped based on some previously defined criteria and by using specified acceptable standards that should be met. This defines the context for a multi-criterion analysis (MCA), with relative weights attached to categories [15] and to acceptable standards, rather than a preference ratio approach in which projects are ordered according to percentage scores for some indicators [16] or a cost-benefit analysis [17] in which projects are ordered according to monetary achievements for all indicators. *Alternatively*, it is possible to use a Delphi method [18,19] or the analytical hierarchy process (AHP; [20–25]) or a group AHP [26,27], a PROMETHEE method [28–31], an ELimination and Choice Expressing REality (ELECTRE) method [32,33],

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a data envelopment analysis [34], an analytical network process [35,36], or an analogy-based estimation [37] to compare alternative design options. In the present study, MCA was chosen because it explicitly accounts for the possibility of multiple competing objectives that must be reconciled. As a result, it allowed me to compare the effects of choosing different methods of defining factor weights on the risk of decision errors.

In this context, let us assume that there are no qualitative indicators [38], so that crisp rather than fuzzy analysis can be applied [39,40]. Moreover, let us assume that all indicators are continuous, so that normalised percentages [41] rather than binary values [42] can be used. Finally, let us assume that there are no weights attached to the acceptable standards (e.g., an internal rate of return greater than 2%; an overall score greater than 50%), so that linear optimisation can be applied [43]. *Alternatively*, it would be possible to use genetic algorithms [44]; however, they produce results that are difficult to explain to stakeholders, and are thus an unsuitable tool for helping stakeholders with competing objectives to reach consensus. Based on these assumptions, our problem consists of maximising the linear sum of weighted percentage scores subject to linear constraints [45] rather than identifying the best combination of options that satisfy a given budget [46]. However, in this approach, the best design depends crucially on the relative weights attached to the multiple criteria by stakeholders and, consequently, depends on the method chosen to estimate the weights, since monetary and time constraints often suggest the need to perform a single estimation of these relative weights.

The *purpose* of this study is to show which methods should be chosen to estimate the relative weights attached to categories of criteria which affect the choice of the best design option. To do so, a *consistent* dataset will be constructed to allow the application of four methods: precisely, two statistical methods and two preference-elicitation methods. Next, an *original* methodology will be developed to improve the logical consistency of the two datasets used for the two different groups of methods. Specifically, I estimate the probability of erroneously rejecting a better design option based on the choice of a given method rather than an alternative or alternatives, within an intuitive overall framework. This approach considers both the satisfaction of predefined acceptable standards and a comparison between options.

2. A consistent dataset from a case study

The MERMAID project aims at designing a sustainable offshore multi-use platform in alternative contexts (i.e., North Sea, Atlantic Sea, Mediterranean Sea, Baltic Sea), where experts and stakeholders are expected to discuss in order to identify technically feasible and socially preferable options: the development of a continuing participative process and the identification of final option designs are equally important within the project. This approach required the involvement of stakeholders in three round meetings (i.e., expressing initial preferences, moulding preliminary designs, judging final designs), where sociologists and economists submitted some questionnaires.

In particular, for the Mediterranean case study, 15 Italian stakeholders were interviewed to determine their preferences related to the sustainability features of a multi-purpose offshore platform: S1 = the Water Plan Office in Veneto Region, S2 = the Harbour Office in Venice, S3 = the National Environmental Agency in Veneto, S4 = the Clam Producer Cooperative in Chioggia, S5 = the Energy Agency in Venice Municipality, S6 = the Naval League in Venice (a nongovernmental organisation), S7 = the Environmental League in Venice (a nongovernmental organisation), S8 = the Hotel Keeper Association in Venice, S9 = SEABREATH (a producer of wave energy converters), S10 = WEMPOWER (a producer of wave energy converters), S11 = the National Alternative Energy Agency in Veneto, S12 = Neural Engineering SpA (a technical consultant), S13 = eAmbiente (an environmental consultant), S14 = the National Research Centre in Venice, and S15 = the Citizen Committee for the Preservation of the Venice Lagoon.

My *first* goal was to determine the perceived importance of 39 features, split into three groups (i.e., goals, demands, and constraints; Appendix B): stakeholders are expected to specify an importance value from 1 (little importance) to 5 (major importance) for each item. Moreover, stakeholders are allowed to specify additional items, grouped into the three categories (i.e., economic, social, environmental), together with a non-answer (i.e., "I do not know"). Finally, stakeholders are informed about which category is attached to each item.

My *second* goal was to determine the perceived importance of three categories (i.e., economic, social, environmental; Appendix C): stakeholders are expected to rank three cards which represent the main economic features (e.g., net annual and induce income), the main social features (e.g., net annual and induce employment), and the main environmental features (i.e., intermediate ecological services such as primary production, nutrient cycling, food chain dynamics; and final ecological services such as reduced alien species, preserved biogenetic habitats). For example, the stakeholder S1 ranked environmental more important than economic issues, and economic more important than social issues (i.e., EnvEcoSoc). Moreover, stakeholders are allowed to introduce blank cards in order to stress the greater importance attached to the feature which is ranked better. For example, stakeholder S7 introduced a blank card between environmental and economic issues and no blank cards between economic and social issues to express that environmental issues are *much* more important than economic ones, and economic issues are more important than social ones (i.e., EnvBEcoSoc). Finally, stakeholders are asked to express their preferences between all couples of features (i.e., Eco vs. Env, Eco vs. Soc, Env vs. Soc) in a double-side scale from 1 to 7 (i.e., 7–1 in favour of the first option, and 1–7 in favour of the second option), where if you like the first option better than the second one, you choose a mark between 7 and 1 on the left side; if you like the second option better than the first one, you choose a mark between 1 and 7 on the right side; if you are indifferent between the first and second option, you choose 1. For example, the stakeholder S1 said 2 in comparing Env and Eco issues, 4 in comparing Env and Soc issues, and 2 in comparing Eco and Soc isssues.

Note that stakeholders were not prioritised, unlike Bendjenna et al. [47], who applied Mitchell et al.'s method to classify stakeholders and used the Croquet integral to integrate the criteria to allow for interactions. Next, I will disregard how and which a final design is achieved within the MERMAID project as irrelevant to this study.

3. Methods for estimating weights

Many methods have been used to estimate relative criterion weights: the revised Simos Procedure (RSP; e.g., [48,49]), the analytical hierarchy process (AHP; e.g., [50–53]), conditional mean analysis or linear regression (LR; e.g., [54]). To these options, factor analysis (FA) was added. Table 1 summarises the pros and cons of these methods, whereas Appendix A provides mathematical formulas and numerical examples for each method.

Within the statistical methods, I chose to apply FA and LR to the same set of answers to questions designed to elicit stakeholder priorities (Appendix B). Before obtaining data, the questions were tested to increase their validity, and any unclear or misleading questions were revised. Within the preference-elicitation methods, I applied RSP and AHP to a consistent set of answers (Appendix C). Note that all four methods are based on expressed preferences, and the questions allowed indifference, whether directly stated