Potentials and limitations of multi-criteria analysis methods in assessing sustainable forest management

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Introduction

European commitments towards sustainable forest management (SFM) are well established at the political level. However, progress in implementing the principles of SFM at the operational scale lags behind. As an option to foster this process, the application of indicators within a multi-criteria analysis (MCA) framework is proposed.

In this contribution, Simple Multi-Attribute Rating Technique (SMART), the Analytic Hierarchy Process (AHP), the Analytic Network Process (ANP), PROMETHEE I/II and ELECTRE III are applied to assess the performances of four management units representing different forestry regimes within a region. A recently developed set of indicators at forest management unit level is used in the analysis.

The implementation of SFM requires a holistic view on multiple goals and values, the awareness of uncertain and inhomogeneous knowledge, the guidance of stakeholder involvement and a spatially explicit long-term perspective. Against this background, the potentials and limits of each MCA method to assess SFM are compared with regard to (i) handling preferences and trade-offs between indicators, (ii) sensitivity in covering complex information on the human-ecosystem interaction, (iii) dealing with thresholds and uncertainty of value information, (iv) participatory planning and group decision making processes, and (v) communicative features.

Methods and Material

The comparative study is based on an indicator set for SFM at forest management unit (FMU) referring to the Ministerial Conference on the Protection of Forests in Europe (MCPFE) and efforts to reduce the original set to a limited choice of key indicators (Vacik & Wolfslehner, 2004; Wolfslehner et al., 2005).

In order to make an indicator set feasible in terms of decision aid at operational level both in evaluation and assessment there is need for instruments that render a diversity of attributes of SFM measurable and thus comparable and cover information on the trade-offs between those features. The application of MCA methods fits perfectly well with an indicator concept that collects information in a structured and compact manner.

Key indicators of sustainable forest management

Based on network analysis and expert opinions a core set of eight key indicators was selected for the comparative study (Table 1). Indicators were condensed in order to delineate the performance of a management extensively.

Table 1: Definition and measurement units of selected key indicators

indicator	definition	measurement unit
planning	quality of management means	score
damaged wood	average decennial share of salvage cuttings compared to overall cuttings	% (m³)
EBIT	average decennial earnings before interests and taxes	€/ha of forest in yield, nominal
harvest/growth ratio	decennial variation from a balanced harvest/growth ratio (=1)	|H/G-1|*100
tree species composition	area proportion of stands comprising natural or semi-natural tree species composition	% (ha) of hemeroby classes 7 (beta-oligohemerob), 8 (gamma-oligohemerob), 9 (ahemerob) of tree species composition only
special ecosystems	maintenance of special forest biotopes and key ecosystems	score
natural regeneration	share of area to be regenerated comprising secured natural regeneration of site-adapted provenances and all representative tree species of an association	% (ha)
training	training activities within a forest enterprise	score

<u>Applied multi-criteria analysis (MCA) methods</u>

For the methodological analysis and the examination of potentials for the assessment of different management strategies five MCA methods are seized.

Analytic Hierarchy Process (AHP)

The AHP by Saaty (1977) is one of the most popular and common MCA methods. The principles of an AHP model are:

- dividing a decision problem into a multi-attributive hierarchical structure (decomposition principle),
- eliciting relative preferences of considerable alternatives by means of pairwise comparisons under constraint of acceptable consistency of the answers (principle of comparative judgment),
- additive synthesis of calculated preferences to an overall priority for each alternative which allows for a cardinal ranking of the evaluated alternatives (synthesis of priorities principle).

Analytic Network Process (ANP)

The ANP (Saaty, 2001) is a generalization of the AHP by dissolving structural boundaries towards a network structure covering interdependencies and feedbacks between elements of different clusters while principally keeping up the AHP-like pairwise comparisons and ratio scales. Priority elicitation is performed within a three-step supermatrix calculation:

- the unweighted supermatrix is built by ratio scales of pairwise comparison inputs on the preferences among interconnected elements
- the weighted supermatrix is gained by multiplying those values with their affiliated cluster weights
- the limit supermatrix is the convergent matrix risen to powers which displays single indicator priorities and overall priorities for alternatives

PROMETHEE I/II

Promethee (Brans et al., 1986) is an exponent of the European MCA school basically describing the degree of dominance of one alternative over the other. Preference functions are to be defined explicitly by indifference and preference thresholds. From the summary of dominance relations regarding individual decision criteria two overall terms are calculated:

- the positive net flow to indicate the degree of dominance of an alternative over the others
- the negative net flow to cover the degree of being dominated by other alternatives
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Promethee I creates a parallel ordinal ranking based on both net flows, whereas Promethee II builds a cardinal ranking of a synthesized net flow.

ELECTRE III

Electre (Roy, 1968) also represents European outranking methods. It calculates a concordance index for each pair of alternatives indicating the degree of non-differentiation. Preference functions are explicitly built by pseudo-criteria by means of indifference, preference and veto thresholds. Veto thresholds may be used as non-compensatory features determining an discordance index of alternatives. Finally, the degree of outranking and the ranking of alternatives is performed by an iterative distillation process.

SMART

SMART (Simple Multi-Attribute Rating Technique) (Edwards, 1971) represents multi-attribute utility theory (MAUT) and is an extension of direct rating techniques. It is based on direct numerical rating values that are aggregated additively. There are many derivates of SMART by now, also including non-additive approaches. In a very basic design of SMART, there is a rank-ordering of alternatives for each attribute setting the best to 100 and the worst to zero and interpolating between. By refining the performance values with relative weights for all attributes a utility value for each alternative is calculated.

Application

Four virtual forest management units in terms of four different forest regimes have been evaluated within this comparative study:

- a secondary spruce forest clear cut regime (MU 1)
- a shelterwood beech forest system with adaptive management (MU 2)
- a coppice management of oak-hornbeam forest with single-tree harvest (MU 3)
- a Douglas-fir age-class system with small clear cuts and segregative conservation strategy (MU 4)

Under the assumption of linear preference functions and equal weights for all indicators all methods indicated that MU 2 and MU 4 would be preferable over MU 1 and MU 3 with slightly varying values. Sensitivity analysis demonstrated that Electre is very insensitive in this kind of setting because linearization is not affine to the immanent distillation procedure and that the interconnections in ANP obviously make the model more insensitive compared to AHP. SMART and Promethee appear most sensitive to changes of indicator weights within this arrangement. All methods express an increasing favour of MU 4 when emphasizing the weights of economic features. Yet, when changing the type of preference functions towards a fuzzy membership function defining performances of each economic success >0 as equally preferred the image is changing towards an explicit preference of MU 2 in all applied methods. Enabling veto threshold in Electre will result in downgrading of a unit, e.g., for a too high degree of artificial tree species composition in MU 4.

Conclusions

The comparative application provokes the question on whom it is to define proper preference functions and weights for the indicators. It can thus be followed that MCA will not work consistently before there is agreement on these items. The problem is that for the concept of SFM preferences cannot be gathered for single decision makers but are to be built on societal consensus. Therefore, it is concluded that MCA methods are powerful catalyst instruments to guide participatory stakeholder processes in the run-up and to demonstrate i) methodological aspects of indicator aggregation, ii) structural dependencies of decision models, iii) the limits of compensation with regard to societal demands, and iv) the sensitivity of stated preferences within a model.

The actual choice of a method depends on case-specific demands. AHP is able to structure a problem hierarchically and to deliver cardinal information on prioritisation in a highly communicative manner but shady in some specific methodological aspects. ANP is to cover more complex evaluation problems but shows drawbacks in transparency of results and in time efforts needed. Promethee is very powerful in the communication of results and easily used while lacking any structural features. Electre is also structurally poor, rather uncommunicative in current application solutions and tends to behave as a black-box to the non-professional user. The non-compensatory veto threshold is the major benefit compared to the other methods. At last, SMART is to be used easily and inexpensively but limited in design. Yet, it bears the potentials for being advanced by features of other methods, e.g., by coupling it with AHP for structuring and pairwise comparisons.

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