Ecological Indicators 43 (2014) 306–314

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

# A decision support tool for assessing scenario acceptability using a hierarchy of indicators with compensabilities and importance weights

Hilko van der Voet[a,*], Gerie W.A.M. van der Heijden[a], Johannes W. Kruisselbrink[a], Seth-Oscar Tromp[b], Hajo Rijgersberg[b], Lenny G.J. van Bussel[c], Esther D. van Asselt[c], H.J. (Ine) van der Fels-Klerx[c]

[a] *Biometris, Plant Research International, Wageningen University and Research Centre, P.O. Box 100, 6700 AC Wageningen, The Netherlands*
[b] *Food & Biobased Research, Wageningen University and Research Centre, P.O. Box 17, 6700 AA Wageningen, The Netherlands*
[c] *RIKILT, Wageningen University and Research Centre, P.O. Box 230, 6700 AE Wageningen, The Netherlands*

ARTICLE INFO

*Article history:*
Received 20 September 2013
Received in revised form 10 February 2014
Accepted 20 February 2014

*Keywords:*
Sustainability
Scenario analysis
Multi-criteria decision making
Compromising
Risk-benefit assessment
Interactive software

ABSTRACT

Choosing between different scenarios commonly requires decision making based on multiple criteria. For example finding the most sustainable agricultural production system requires evaluation of many indicators in fields as diverse as environment, animal welfare and economics. A new and transparent method to such problems based on piecewise linear functions is described, and compared to other approaches. This paper presents a decision support tool which allows to (1) group indicators in a hierarchy, (2) define the acceptability of indicator values between unacceptable and desirable values, (3) define the relative importance of indicators, and (4) combine the individual indicators' acceptabilities using various degrees of compromising into a final acceptability score for each of the investigated scenarios. The tool contains a visual module to study the comparison of scenarios in the bivariate case, which allows to get familiar with the concepts behind the balancing of indicators. The developed method and software tool are useful for decision support in processes where policy makers and scientists are interacting to arrive at optimal decisions.



## 1. Introduction

Decision makers, both in industry and government, are confronted with the need to balance different dimensions of acceptability when comparing possible scenarios for future implementation. For example, when deciding on acceptable future food production systems, sustainability has become an important goal of decision making, which is a multi-dimensional concept dealing with social, environmental and economic dimensions. These main dimensions of sustainability are commonly referred to as People, Planet and Profit (e.g. Kleindorfer et al., 2005). In addition, each of these groups can be decomposed into multiple other (sub)dimensions or themes, e.g. health and ethical aspects for People, and land use and greenhouse gas emissions for Planet. Consequently, sustainability and therefore also the acceptability of proposed decisions are umbrella concepts and in general cannot be measured as a single number. Therefore, when comparing scenarios for a future decision, the available data about quantitative indicators or criteria that partially describe the acceptability of proposed scenarios should be combined. For example, when considering options for different egg production systems, chosen sustainability indicators may vary from the dioxin content of eggs (People), to the greenhouse gas emission per produced egg (Planet), and the farmer's income (Profit) (de Boer and Cornelissen, 2002). It is difficult to assess the acceptability of a proposed scenario considering such different dimensions. In rare cases it may be possible to convert all indicators to a common scale unambiguously, for example if all indicators could be translated to monetary value. In such a case the individual scores can be added to obtain an aggregate acceptability.

The focus of this paper is on the more common case, where there is no unambiguous procedure to convert all indicators to a common scale. Typically such a conversion is considered to go beyond objective science as such, and requires value-driven judgments. Decision makers need to extract all relevant science-based information from scientists, and subsequently integrate this in an all-encompassing risk-benefit assessment also based on a subjective weighing of personal and/or public normative preferences. Questions that need to

* Corresponding author. Tel.: +31 317480811.
*E-mail address:* hilko.vandervoet@wur.nl (H. van der Voet).

http://dx.doi.org/10.1016/j.ecolind.2014.02.022
1470-160X/

be addressed are: What is the relative importance of the different indicators, e.g. is greenhouse gas emission more important than farmer's income? If so, how much? What are reasonable limits for acceptability, e.g. what should the income of a farmer minimal be in order to be considered sustainable? Is a trade-off between different aspects of sustainability possible, e.g. should one be prepared to accept a higher than desirable energy use if that is combined with a very small and desirable ecological footprint in terms of land use?

The increased availability of quantitative data leads to cases where different indicators exist for more or less the same concept. For example, animal health may be represented by percentage sick animals, percentage bone fractures or percentage mortality. It is then a relevant question if in an analysis based on large numbers of indicators, *all* such indicators should show acceptable values. Such a requirement may lead to a negative verdict on all investigated scenarios due to occasional low values for any of the indicators. An alternative approach is to consider some sort of weighted average of all measured indicators for a theme such as animal health. In some situations such averaging is however not allowed, for example if legal requirements have to be met for individual indicators. It is, therefore, essential that decision makers can make appropriate choices for each group of indicators.

In multi-criteria decision making (MCDM) decision makers have to be specific on three aspects: (1) for each indicator they have to specify a degree of *acceptability* for realised values, (2) the relative *importance* of indicators with respect to one another, and (3) the *compensability* of indicators, which indicates to what extent one indicator may replace another in terms of scenario acceptability judgement. In addition, it may be useful to specify a *hierarchy* with intermediate concepts (such as Animal Health) between the quantified indicators at the lowest level and the overall scenario acceptability at the top. A hierarchy can be sketched as an inverted tree-like structure, with all measured indicators as the leaves, intermediate concepts as nodes, and overall acceptability as the root of the tree.

Methods that deal with integrating multiple criteria are known under the general name of MCDM or multi-criteria decision making, sometimes also referred to as MCDA or multi-criteria decision analysis. For a review in the context of sustainability planning see Pokehar and Ramachandran (2004) and Rowley et al. (2012). Well-known MCDA methods include the weighted sum method (WSM), the Analytic Hierarchy Process (AHP, see e.g. Saaty, 1990), and outranking methods such as Promethee and Electre (Brans and Vincke, 1985; Roy, 1991). Such methods all assign importance weights (or priorities) to the separate indicators (criteria) and criteria are combined with linear methods. However, linear weighing is not always acceptable, for example in the case of legal limits.

Compensability, also known as compromise or compensation, is a property of a group or subgroup of indicators. A lower score on one criterion is compensated by a higher score on another. On the other hand, non-compensable indicators all have to meet their own criteria for acceptability. MCDM methods allowing for both importance weights and compensability have been proposed in various fields (Yu, 1973; Duckstein and Opricovic, 1980; Opricovic and Tzeng, 2004, 2007; Scott and Antonsson, 1998, 2005).

In practice, decision makers have to specify importance weights as well as the degree of allowed compromising. Whereas the setting of importance weights has been generally accepted as a necessary and useful step in the MCDM process, it has been found very difficult to elicit opinions on an appropriate value of a compromising parameter $p$ because

(1) in the standard methods the compromising parameter $p$ is the order of a weighted norm (see Eq. (3) in Section 4), which is very difficult to understand for most decision makers, and
(2) the desired degree of compromising in a defined hierarchy of indicators is often not the same for different subgroups.

The purpose of this paper is to present a transparent, objective, and quantitative MCDM methodology addressing both compensabilities and importance weights in an integrated hierarchical system of indicators. We define a mathematically simple and well-performing method to address compensability.

The methodology allows for the integration of science-based knowledge and normative, 'political' choices that are not supported by science and for which only the decision maker can be responsible. An important property of the proposed methodology is its transparency: all choices (and non-choices) made are documented and can be inspected and re-evaluated. In this way, MCDM will be a learning process, where both new knowledge and new norms can be introduced to update previous assessments. This paper describes the technical issues of the methodology. A more general protocol approach will be separately described (van Asselt et al., 2014).

The structure of the current paper is as follows. In Section 2 we present an operational definition for scenario acceptability, and explain the proposed method for balancing acceptability across multiple dimensions. Further, a software tool for performing the calculations is described. In Section 3, an illustrative example on sustainability assessment of egg production systems is presented. In Section 4 the proposed method is compared to other methods, and Section 5 summarises the main points.

## 2. Methods

We first define scenario acceptability for a single indicator, focussing on the roles of scientists and decision makers. Then, we propose a method for assessment based on two or more indicators. Compensabilities are defined as values between 0 and 1 at any (sub)group level in the hierarchy of indicators. For the use of the method in practical decision making cases, we developed a user-friendly software tool that can be applied by (a team of) decision makers and scientists. The software has a module to let decision makers experiment in a simplified (bivariate) setting with the consequences of choosing compensability and importance weights for the acceptability scores.

### *2.1. Acceptability for a single indicator*

For acceptability assessments using MCDM, usually indicators (criteria) are derived that can quantify the different dimensions of the problem. We assume that a list of such indicators has been derived and quantified. The derived indicators need to be evaluated against threshold levels to make them meaningful. To define the minimum acceptable quality, the simplest approach would be to set a single limit value for each indicator. This single limit would classify each scenario value for this indicator as acceptable or unacceptable.

However, in practical situations limits cannot always be defined so clear, therefore it may be useful to see scenario acceptability (also called preference; Scott and Antonsson, 1998) as a matter of degree, arbitrarily defined as a value between 0 and 1. Such graded acceptability scores allow both gradual (fuzzy) and sharp distinctions between optimal and unacceptable indicator values.

In our approach, we defined three values for each indicator: an unacceptable value ($U$), a reasonable value ($R$), and a desirable value ($D$). These limits are often 'value-driven', and have to be set by the decision maker. Scientists may help in selecting suitable values, for example by summarising legal standards or policy documents. The