



## Analysis

## Critical Analysis of Methods for Integrating Economic and Environmental Indicators

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## ABSTRACT

The application of environmental strategies requires scoring and evaluation methods that provide an integrated vision of the economic and environmental performance of systems. The vector optimisation, ratio and weighted addition of indicators are the three most prevalent techniques for addressing this need.

The vector optimisation evaluates the original indicators independently in a dominance check. No real integration is performed, as the method seeks the optimisation of both indicators at once. This technique reveals win-win situations and can also identify, but not solve, the trade-off situations involved in economy versus ecology.

The ratio method establishes a relation among the original indicators. This concept is suitable when one dimension has to be optimised against the other. A number of conceptual problems in the definition of the sense of direction of the ratio method make its interpretation ambiguous.

The weighted-addition provides a fair evaluation of the integrated performance of a system, with regard to the decision-maker's preference for ecology and economy. This is crucial to reconcile trade-offs between conflicting criteria. Special attention must be paid to the selection and definition of weighting factors, being a source of potential inconsistencies.

## 1. Introduction

Throughout the last half century, global population and economic growth have contributed to the progression and expansion of environmental problems. In response, environmental management became a topic of concern for individuals, businesses and governments. Management strategies evolved to embrace an integrated vision that advocates for merging economic growth with social and environmental problems through institutional change (Colby, 1991). In this context, the link between economic and environmental gain is seen as necessary in order to facilitate the ecological advantage (Boons, 2009).

Eco-development strategies and, among them, eco-efficiency (Colby, 1991) adopted this perspective, which applies tools and methods to practice. A number of scoring and evaluation methods allow for an integrated assessment of systems, which enables decision-making processes and supports production and consumption choices. The integrated vision requires the methods to face and solve the trade-offs that are present between economic and environmental costs and gains, which certainly complicate the decision-making processes.

In the scientific and business domains, there is poor alignment and not much consensus when it comes to integrating economic and environmental indicators. Large variability in integration methods is found due to three main differences:

- Firstly, there is no agreement about the selection of the indicators to represent ecology and economy. For instance, with respect to the environmental dimension, some authors focus on climate change impacts, while others calculate a loss of species diversity.
- Secondly, the indicators are differently prepared for integration. Different authors use different references within the measurement scale, defining absolute or relative indicators (e.g., Dyer, 2005); and some methods require normalisation whereas some others don't (e.g., Figueira et al., 2013).
- Finally, the combination rule that is used to achieve the actual integration of the indicators differs. Some authors (e.g., Lippiatt, 2007) use a weighted aggregation, others divide the two separate indicators (e.g., Huppes and Ishikawa, 2005b), and there exist even

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more complicated aggregation formulas (e.g., Böhlinger and Jochem, 2007).

This article reviews and analyses the methods that combine indicators of economic and environmental performances of systems. The scope of the study strictly focuses on the integration techniques, rather than on the selection and preparation of indicators. The main purpose is to explore from a theoretical perspective the attempts that have been made to combine economic and environmental indicators, and to draw conclusions about the strong and weak points of such approaches in relation to the realm of applicability.

The research builds on existing literature in the identification and selection of methods for review and the relevant criteria to assess them. A theoretical study of the selected methods, which analyses their basic characteristics and the common operations that influence them, is performed. This is supported with reflections and observations found in academic literature. A qualitative assessment draws together the descriptions of the techniques, the relevant criteria for assessing their performance and the theoretical analysis. Conclusions and recommendations are subsequently derived for the appropriate use of the methods.

The article is structured as follows. Section 2 provides an overview of current methods that integrate environmental and economic indicators and Section 3 explores the consequences of common operations applied to the indicators. The results of the review are discussed in Section 4, therefore presenting a complete assessment of the techniques regarding the different criteria that define their performance. Finally, Section 5 offers conclusions and recommendations for the successful implementation of the analysed methods.

## 2. Description of the Three Methods

This section introduces the most widely-used methods that integrate economic and environmental indicators, as present in the literature. We have organized the approaches into three groups (references are postponed to the sections in which we discuss the three approaches in detail):

- Methods that do not calculate a composite indicator value from the economic and environmental indicators, but that nevertheless integrate the two aspects. This is primarily a graphic-based method, but it also includes methods that are based on Pareto efficiency. These methods will hereafter be referred to as vector optimisation.
- Methods that calculate a composite indicator value by dividing the value of the economic indicator by that of the environmental indicator, or the other way around. Many eco-efficiency indicators are based on this approach. In this article, we refer to them as ratio methods.
- Methods that calculate a composite indicator value by adding the values of the economic and the environmental indicators, possibly after a weighting step. Some multi-criteria methods (MCDM) are based on such a weighted-addition method.

In addition to the three groups mentioned, one sometimes sees methods that take a different approach, although most-often in a slightly different context (e.g., within the environmental domain). For instance, the Life Planet Index consists of a geometric mean of biodiversity indexes for terrestrial, freshwater and seawater ecosystems (Böhlinger and Jochem, 2007). Within the multi-criteria decision-making field, many methods are available that can also be used to integrate the economic and environmental dimensions (Cinelli et al., 2014 and Diaz-Balteiro et al., 2016). Among them, the TOPSIS method uses weighted Euclidean distances to rank alternatives (Lu et al., 2007). The review of the literature shows a limited use of these and other methods to integrate economic and environmental indicators and therefore, they are excluded from the scope of this study.

### 2.1. Original Indicators

In presenting our findings, we must first harmonize terminology and notation. In order to keep a consistent criterion throughout this article, a negative sense of direction is defined for the original indicators, standing for economic cost and environmental impact. A high indicator means a high cost or environmental impact, and therefore the optimal alternative has the lowest score. We refer to this as a *lower is better* criterion. The analysis, results and conclusions are trivially rephrased for other conventions.

Mathematical notation is as follows. The economic indicator is written as  $M$  and the environmental indicator as  $E$ . For a specific system (e.g., product, country, company), an index  $i$  is added; thus  $M_i$  refers to the economic impact of system  $i$ . In a practical situation, a decision-maker is confronted with a set of alternatives ( $i = 1, \dots, n$ ) where each alternative can be indicated by coordinates  $(M_i, E_i)$ . Our analysis below will focus on trying to rank the alternatives in order of preference. Thus, binary operators ( $>$ ,  $<$ ,  $\geq$ ,  $\leq$  and  $\sim$ ; see Binmore, 1992 and Mas-Colell et al., 1995) will indicate the relation between two alternatives. For example  $(M_1, E_1) > (M_2, E_2)$  (or alternatively:  $1 > 2$ ) indicates that alternative 1 is preferred to alternative 2, and  $1 \sim 2$  that there is an indifference relation between the two. Observe that  $1 > 2$  does not necessarily mean that  $M_1 < M_2$  and that  $E_1 < E_2$ , but rather that  $\pi(M_1, E_1) > \pi(M_2, E_2)$  (or alternatively:  $\pi_1 > \pi_2$ ), where  $\pi$  represents a preference function or variable. Notice that the negative sense of direction discussed above implies that preference (so  $>$ ) corresponds to smaller than (so  $<$ ).

As stated in Section 1, the preparation of indicators prior to integration is outside the scope of this research. Nevertheless, it is necessary to briefly discuss the different forms that an indicator can present, because this may have a relevant influence on the performance of the integration method.

Before integration, the indicators may be subject to a normalisation process, aiming at contextualising and better understanding the magnitude of the result and/or removing the influence of an arbitrary choice of measurement units (Pollesch and Dale, 2016). Several normalisation procedures are applied. Within this article, we refer to the quotient of the indicator value by a normalisation reference, as in Eqs. (1) and (2).

$$M'_i = \frac{M_i}{M_{ref}} \tag{1}$$

$$E'_i = \frac{E_i}{E_{ref}} \tag{2}$$

where  $M_{ref}$  and  $E_{ref}$  can be external references such as the total value of the indicator for a given geographic area and time period. Alternatively, internal normalisation is used when the decision-maker is confronted with a set of alternatives, and uses the values of (part of) it to derive a baseline scenario, which is used as normalisation factor. Examples of internal normalisation factors are the value of the indicator for one of the alternatives (e.g. best or worst performing) or the average value of the alternative in the set, as in Eq. (3).

$$M_{ref} = \max_{i=1}^n M_i \tag{3}$$

The original indicators are sometimes contextualised by making them relative to a baseline (e.g. one of the alternatives in the alternative set). Accordingly, we distinguish between absolute (original) and relative indicators.

A graphic representation is usually adopted and is generally regarded as a useful means to visualise the integration of economic and environmental indicators. In this article, we will concentrate on using a two-dimensional graph, where the axes denote the environmental and economic indicator. We consistently present the economic indicator on the abscissa and the environmental one on the ordinate. In the sections below, a common data set is used to illustrate the graphic

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