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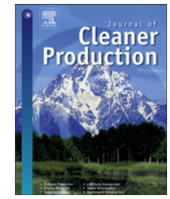

Review

Review of combined approaches and multi-criteria analysis for corporate environmental evaluation

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A B S T R A C T

This paper reviews the advantages of combining complementary environmental evaluation tools – ecological footprint, life cycle assessment and environmental risk assessment – that were identified as encompassing the most significant features that should be considered in corporate-related appraisals. Together, these tools evaluate key aspects of environmental sustainability, such as depletion of resources, environmental impacts and human health preservation, and their combined application was found to produce more comprehensive analyses and ensure that relevant issues were not being disregarded.

The joint application of complementary tools implies a set of indicators for which a compromise solution must be found. In this respect, the applicability of multi-criteria analysis in decision support systems was also reviewed, restricting the areas of application to the following 4 categories: 1) industry-related applications, 2) energy decision making, 3) waste management and treatment and 4) wastewater treatment. Outranking methods were identified as those more widely employed in environmental problems when users were asked to select from a number of discrete alternatives. The incorporation of fuzzy reasoning in decision making has increased significantly in most recent applications, revealing the need to incorporate such features in a problem characterized by imprecision and subjectivity. Although not always conducted, sensitivity analyses were also essential to enhancing the robustness and reliability of such studies.

It was concluded that multi-criteria analysis would benefit from the previous application of standardized methodologies as those proposed in this review to derive criteria. Hence, the most relevant environmental burdens and their severity would be identified and characterized in a previous step, helping to reduce the complexity of the decision-making problem and the possibility of duplicating effects. The scientific basis would be enhanced, making the selection of criteria and establishment of weights less arbitrary.

1. Introduction

There has been increasing regulatory pressure on many industries to improve their environmental performance, including the Integrated Pollution Prevention and Control Law (Spanish Government, 2002), the Integrated Policy Product –IPP (European Commission, 2003), the REACH Regulation (European Commission, 2006) and the Directive 2004/35/CE on environmental liability (European Commission, 2004) at the European level. To combat this pressure, companies have explored new management strategies based on voluntary administrative instruments (ISO 14000, EMAS, Eco-Label, Corporate Social Responsibility, etc.), which have been well-received by stakeholders (Hertwich et al., 1997).

Ecodesign is a broader strategy that can be employed at the corporate level to comply with previous laws and management instruments, and can be defined as the systematic introduction of environmental concerns during product design and development (AENOR, 2003). The objective of this strategy is to create sustainable solutions that satisfy human needs and desires (Karlsson and Luttropp, 2006). Hence, ecodesign must incorporate two main aspects (Herva et al., 2011a), design for sustainability and design for health and safety, the latter being particularly affected by the REACH Regulation (Askham et al., 2012). The indicators available to approach this task provide complementary visions of the studied scenario and, in most cases, more than one indicator can be applied at a time (Byggeth and Hochschorner, 2006; Herva et al., 2011b). The difficulty often arises from the lack of available criteria to select appropriate indicators for each case, rather than from the scarcity

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of scientifically sound methodologies (Niemeijer and de Groot, 2008).

Indicators such as the pressure on resource use, complementary environmental impacts and risk derived from exposure to substances likely to pose damage to human health and ecosystems should be evaluated from a life cycle perspective to obtain an overview of the environmental burdens that may occur at the corporate level. The analysis presented in Section 2 focused on three complementary types of indicators that fulfilled the requirements of design for environmental sustainability and safe design, and they were representative of the different categories reviewed in a previous paper (Herva et al., 2011b), Ecological Footprint (EF), Life Cycle Assessment (LCA) and Environmental Risk Assessment (ERA). The goal of the analysis was to better understand the relationships between these different indicators, assess the appropriateness of their application in diverse situations and provide an overview of the options for their combined application. The applicability of Multi-Criteria Analysis (MCA) methodologies as a tool to handle a set of indicators for the environmental or sustainability evaluation of corporate-related applications was also explored and reviewed in this paper. MCA applications were applied mainly to sustainability appraisals; that is, they included indicators from economic, social and environmental categories as well as technical criteria.

A literature review was conducted using scientific search engines and restricting the papers selected to those from journals indexed in recognized databases (e.g., JCR) and that were published after 2000. In Section 2, the keywords ecological footprint, life cycle assessment (or its acronym, LCA) and risk were combined to search for integrative proposals related to corporate applications in the literature. In Section 3, the general term multi-criteria analysis or its acronym, MCA, was used as the keyword in an initial broader survey of the literature and accompanied by other specific terms such as environment and sustainability. Later, the search was refined and focused on the specific MCA techniques reviewed in the paper, and these techniques' acronyms were included as keywords (e.g., AHP, ELECTRE, and PROMETHEE). Searches were also conducted using the topics discussed later in the paper, all of which were connected to the environmental evaluation of production processes or products.

2. Framework for the complementary application of EF, LCA and ERA

2.1. Combination of EF and LCA

The EF has been recognized as an appropriate screening indicator to track the environmental performance of processes and products (Huijbregts et al., 2007; Herva et al., 2008). It has been especially valuable for communicating results and has established minimum criteria in sustainability appraisals (Kitzes and Wackernagel, 2009). However, this last characteristic means that key environmental aspects can be disregarded because the EF methodology does not permit their evaluation, which may be a drawback when different alternatives of processes or products are evaluated because it can lead to erroneous comparative analyses and provide misleading guidance. Nevertheless, this problem does not invalidate the application of EF but rather indicates the need for complementary use of other indicators.

In such situations, it has been particularly interesting to complement EF studies with certain LCA indicators to assess the aspects excluded from EF estimates (e.g., emissions other than CO_2 and the release of toxic pollutants). The application of this methodology has also been proposed when a more in-depth analysis is required for a particular functional unit, thus helping to identify more sustainable solutions or the best available techniques (Azapagic, 1999).

There exists a strong link between EF and LCA. In fact, the Ecological Footprint Standards (Global Footprint Network, 2009) define two approaches to estimating the EF of products, process-based life cycle assessment (P-LCA) and environmentally extended input–output life cycle assessment (EEIO-LCA). The former is based on the aggregation of individual product evaluations and requires compliance with LCA ISO 14040 and 14044 Standards, while the latter is based on the allocation of national input–output tables. In both cases, different boundaries for the life cycle (i.e., cradle to grave, cradle to gate, etc.) are permitted as long as they are clearly defined in the study. EF assessment of an organization, regardless of scope, is conducted in a "bottom-up" manner based on a combination of individual product footprints.

This life cycle perspective has been used by different authors to perform EFs of products and processes, such as mobile phones (Frey et al., 2006), buildings (Bin and Parker, 2011) and the tourism industry (Castellani and Sala, 2011). Both methodologies (EF and LCA) have also been applied and compared in case studies of dairy production systems (Thomassen and Boer, 2005) and broiler feed production (de Alvarenga et al., 2011). The most exhaustive comparative study has been conducted by Huijbregts et al. (2007), in which the authors identified the existence of a relationship between EF and LCA when the EcoIndicator (EI) 99 was employed to evaluate a large variety of products and services consumed in the western economy. It was found that the majority of the products had an EF/EI ratio of approximately 30 ± 5 m^2-eq yr/ecopoint, but deviations occurred when products with high mineral consumption and process-specific metal and dust emissions were evaluated. These results suggest that the EF methodology should be complemented with LCA when evaluating these types of products or processes involving these raw materials and emissions so that the corresponding environmental impacts can be properly accounted for.

2.2. Risk evaluation with the EF approach

One of the main drawbacks of the EF methodology is its inability to evaluate the impact of many hazardous or toxic pollutants, which are systematically excluded from EF estimates (Herva et al., 2011b). In contrast, the Dissipation Area Index (DAI), a methodology belonging to the EF family, includes a series of assimilation factors for a variety of substances released into different compartments, such as carbon dioxide, ammonia, methane, sulfur oxide and lead in air and nitrate, phosphate, copper and iron in water (Eder and Narodoslawsky, 1999). Herva et al. (2010) have developed a methodology to assess the footprints of hazardous and non-hazardous wastes by considering a closed cycle modeled with a plasma process. Both approaches allow for the conversion of these output flows into area requirements, but the effects of their toxicity and hazardousness are not evaluated. Instead, complementary indicators must be applied to capture their impact, such as those from the ERA (Kitzes and Wackernagel, 2009), as has been performed by Herva et al. (2011a, 2012) for the ecodesign of products. In this respect, Stoeglehner et al. (2005) have made an interesting proposal to assess the EF of nuclear energy on the basis of a life cycle assessment approach by estimating the area likely to be adversely affected by the production of electricity with nuclear energy systems.

2.3. LCA and ERA: complementary approaches to toxicity

LCA claims to offer an integrative assessment of a process or product. It is vital to apply a life cycle perspective when studying the environmental impacts of products and processes to avoid problem shifting among life cycle stages or geographical areas