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An integrated approach for green design: Life-cycle, fuzzy AHP and environmental management accounting

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ABSTRACT

The growing awareness of environmental issues has made the design of eco-friendly products a critical task for modern businesses. Almost all the costs and the environmental performance of a product over its life-cycle are determined in its design and development phase. The selection of alternative green designs is, however, a major challenge in today's competitive environment. The increasing pressure on time-to-market conflicts with the analytical approach typically required when using conventional environmental management accounting (EMA) tools such as Life-Cycle Assessment (LCA) and Life-Cycle Costing (LCC). This paper introduces a comprehensive method that integrates the LCA and EMA concepts, fuzzy logic and Analytical Hierarchical Process (AHP), to measure the environmental and organisational performance of different designs. We propose a screening model to help designers reduce their reliance on LCA and present a case study to demonstrate that this approach provides a systematic method of evaluating alternative designs and identifying product design improvement options. The measurement approach presented in this research can help companies reduce development lead time by screening out undesirable design options. More importantly, the approach can be modelled with the mere use of an Excel spreadsheet, which means limited resources are needed to implement the proposed method.

1. Introduction

The last decade has witnessed a significant increase in studies related to environmental concerns, which is unsurprising given the growing awareness of the prevailing issues. Many of these studies pinpoint the development of various technologies that can reduce a variety of negative environmental impacts such as carbon emissions. However, the influence of operational activities, due to their wide scope and the extensive number of processes, should not be underestimated. More specifically, production and manufacturing activities are primary contributory factors that notoriously consume not only huge quantities of resources but also generate an enormous amount of undesired outputs and remain a challenge to many companies (Beamon, 1999). Unfortunately, as generalised in Fig. 1, these negative effects are often not taken into consideration.

This figure is of course a simplified version for illustrative purposes only, as in reality, feedback is possible (for example, in recycling activities). Adequate measuring techniques are essential to assess the impacts of production on the environment,

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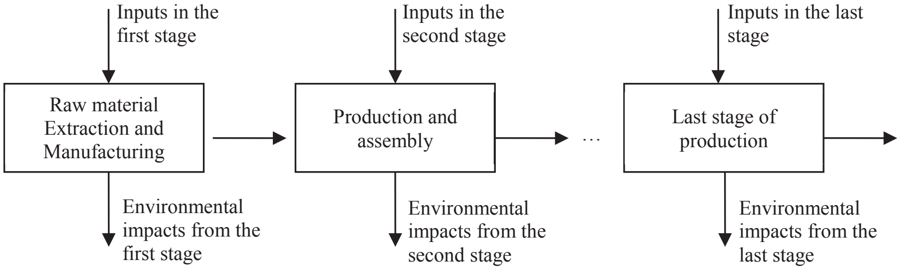

Fig. 1. Life-cycle approach to measure environmental impacts of a product over its production cycle.

which can then be reduced with relevant remedial actions (Bai, Sarkis, Wei, & Koh, 2012; Miemczyk, Johnsen, & Macquet, 2012). There are various methods to tackle this problem from different perspectives. One concept to help reduce these impacts is taking preventive actions in the product and production design stage (Dangelico & Pujari, 2010). Designing a green product and the associated production processes is without doubt a key concern since the design affects all the subsequent production activities and hence the amount of undesirable outputs (Luh, Chu, & Pan, 2010). This effect also extends to sustainability. Assessing environmental impacts at the design stage, while also taking into account stakeholder concerns, is indicative of a good sustainable supply chain measurement system (Björklund, Martinsen, & Abrahamsson, 2012).

The costs and environmental performance of a product are determined in the early stages of R&D and the availability of environmental and economic information is key in the development of eco-friendly products (Rebitzer, 2002; Sroufe, Curkovic, Montabon, & Melnyk, 2000). Environmental Management Accounting (EMA) has recently been proposed as a relevant tool to inform environmental management processes (Bartolomeo et al., 2000; Burritt, Hahn, & Schaltegger, 2002). Within the wider sustainability accounting domain, EMA provides both financial and non-financial information that can help companies improve their environmental and economic performance (Bennett, Rikhardsson, & Schaltegger, 2003; Deegan, 2003). EMA also foresees including not only past but also future-oriented information, thus playing a significant role in long-term planning and in the appraisal of future projects (Burritt et al., 2002). Despite this general recognition, only recent studies have started explicitly to address the role of EMA and related tools in supporting ad hoc future-oriented processes such as innovation (Ferreira, Moulang, & Hendro, 2010) and new product development (Lang-Koetz, Beucker, & Heubach, 2009). Within this research area, the Life-Cycle Assessment (LCA) and Life-Cycle Costing (LCC) approaches have received increasing attention and been interpreted as fundamental tools of the EMA framework (Burritt et al. 2002; Viere, von Enden, & Schaltegger, 2011). In particular, LCA – also called 'cradle to grave' analysis (Soosay, Fearne, & Dent, 2012) – quantifies the environmental impacts (i.e., problematic and undesirable outputs) of a product's entire life-cycle and covers raw material extraction (which affects procurement), production, distribution, all the way down to the end-of-life stage (Guinee et al., 2011).

In line with Fig. 1, LCA considers the aggregative inputs (such as resources and utilities) and the undesirable outputs in relation to environmental effects covering the entire product life-cycle. Product designers can thereby quantify the environmental impacts of their designs, selecting different design options when such factors are critical to, for example, green brand development. These analyses can highlight the critical components or processes of a product so that preventive and corrective actions can be taken. LCA can be applied in various fields such as bio-fuel (Lardon, Helias, Sialve, Steyer, & Bernard, 2009), textiles (Steinberger, Friot, Jolliet, & Erkman, 2009), electronic products (Yung et al., 2011), farming (Liu, Langer, Høgh-Jensen, & Egelyng, 2010) and the wine industry (Soosay et al., 2012), to name but a few.

This paper proposes an approach that combines the LCA concept with Fuzzy-AHP (FAHP) to measure the "greenness" of product and production designs. We present this method through the EMA approach as a tool that is better able to support ad hoc, future-oriented decisions. Our aim is to provide a practical tool to perform pre-LCA screening for a subsequent full LCA. The method we propose can easily be used by practitioners to obtain valuable information to evaluate various product and production design options. More importantly, the approach can be modelled with the mere use of an Excel spreadsheet and is therefore very affordable for all organizations but particularly for small and medium enterprises (SMEs). The model can screen out ineffective designs and reduce the need to undertake full LCA for all options; in other words, our method complements LCA and is expected to strengthen the role of EMA in appraising new "green" products. We test the method through a case study of an electronic product since the waste generated by such products is not only vast but also toxic (Kiddee, Naidu, & Wong, 2013). This is also why the European Union issued a Directive to govern the end-of-life treatment of Waste Electrical and Electronic Equipment, known as WEEE (European Council, 2003).

The paper is structured as follows. Section 2 presents a review of recent literature followed by a detailed discussion in Section 3 of the decisional problem in a hierarchical structure. Section 4 presents the FAHP method while Section 5 applies the method to the case study and presents the implications, which we address in Section 6. Section 7 concludes the paper.

2. Literature review

Addressing environmental issues in the operations management domain is not a new topic, although early contributions focus more on high-level management practices (Lu, Wu, & Kuo, 2007). Lamming and Hampson (1996), for example, propose