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Assessing the environmental footprint of manufactured products: A survey of current literature

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ABSTRACT

Environmental sustainability has become a high priority for many industries. While the growing concern to preserve our environment is critical to society and consumers, industries can also realize additional benefits of higher production efficiency and lower costs with this emphasis. Current research has focused on identifying carbon maps of supply chains by assessing the carbon footprint of products. Little work has been done on establishing methodologies that standardize these attempts. This paper surveys existing approaches, identifies commonly utilized methodologies and looks beyond carbon criteria for sustainable manufacturing. The challenges of establishing a comprehensive and standardized index based on all the manufacturing aspects, allowing companies to quickly assess the environmental footprint of their manufactured products, are debated. This exploratory paper also discusses possible approaches to alleviate shortcomings in current research in this area.

1. Introduction

With the growing concern about climate change and environmental issues, sustainable manufacturing and efficient resource utilization are gaining popularity with significant potential in theoretical study as well as industrial applications. The most commonly accepted definition of sustainability and sustainable development can be considered as "passing on to the future generations a stock of capital that is at least as big as the one that our own generation inherited from the previous generations" (http://www.thetimes100.co.uk/case-study–working-for-sustainable-development-primary-industry – 65-211-2.php). A more focused definition of sustainable manufacturing was developed as part of the U.S. Department of Commerce report on sustainable manufacturing, where it is defined as "the creation of manufactured products that use processes that are non-polluting, conserve energy and natural resources, and are economically sound and safe for employees, communities, and consumers" (Westkämper and Alting, 2000). Therefore, sustainable manufacturing entails implementation of a range of initiatives at the enterprise level, beginning with the design stage and throughout the product's lifecycle to achieve the aforementioned goals. As illustrated in Fig. 1, such an approach would necessarily acknowledge that development in the social, environmental and economic dimension is of equal importance toward a sustainable progress of being responsible in each these areas (Azapagic and Perdan, 2000; IUCN, 2006).

A management practice akin to the approach described above is the triple bottom line (TBL) (Bob, 2002; Elkington, 1997). The approach endeavors to gage economic, social and environmental performance of a corporation over a period of time with the intention of being responsible toward the aforementioned. The TBL is therefore composed of the 3 Ps, 'Profit, Planet and People'. However, the approach is crippled by the lack of an adequately quantifiable measure that assesses impact of corporate policy on the 3 Ps concurrently. Wiedmann and Barret (2010) discuss the shortcomings of environmental footprint (EF) as a measure and conclude that EF may be used as a qualitative policy framing tool but not as a quantitative decision parameter, which might be of higher relevance to success of TBL as described above.

Against the background of these definitions of sustainability, this article focusses on approaches for gauging the environmental impacts (EI) of products which is often a much needed metric for defining and optimizing sustainability initiatives.

As part of the move toward sustainable manufacturing, it is important for designers and engineers to be able to quantify new product designs as well as new manufacturing processes from the perspective of environmental impacts. The development of the concept of carbon footprints (CF) is an important first toward a universal measure of the EI caused by the product; however, it is not comprehensive or sufficient. Although CF is related to the emission of Greenhouse gases, only carbon dioxide levels are

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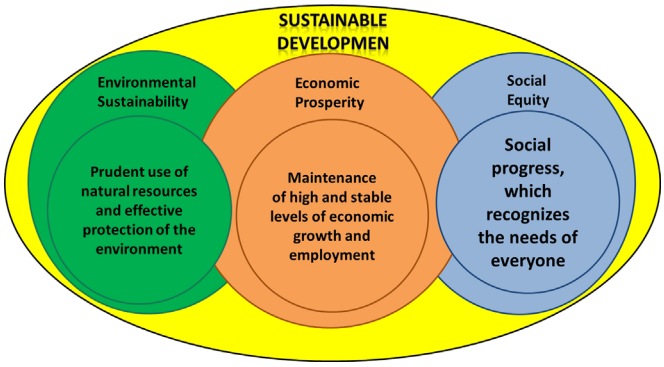

Fig. 1. The three pillars of sustainable development (IUCN, 2006).

gaged in many cases. Furthermore, to exemplify the inadequacy of this measure, we present the example of deforestation. Although direct Greenhouse Gas (GHG) emissions might be negligible in this event, there will be significant negative environmental impact. Another example is the manufacture of canned seafood, a process with little GHG emission but very significant marine ecological impact. CF calculators generally work by accepting characteristics of individual behavior and by returning an amount of carbon dioxide emitted as a direct result of such behavior. Many website CF calculators are available on internet and Padgett et al. (2008) provide a survey of a few of these and find that although these calculators employ similar approaches for CF estimation, their results often vary by several metric tons per annum per individual activity. These variations may be due to differences in calculating methodologies, behavioral estimates, conversion factors, or other sources. However, the lack of transparency makes it difficult to determine the specific reasons for these variations and to assess the accuracy and relevance of the calculations. Sundarakani et al. (2010) discuss Eulerian and Lagrangian modeling of carbon footprints across the supply chain. Based on their model, they mark the EIs of various stages of the supply chain as acceptable, borderline or unacceptable.

Assessing such an index nonetheless increases awareness of sustainable concerns; it can also help realize additional benefits of higher production efficiency and lower costs. The growing pressure from the government and regulatory agencies also helps ensure that many industries are gradually heading toward the direction of sustainable manufacturing.

Existing research has focused on identifying carbon maps of supply chains by assessing the carbon footprint of their products. Our paper surveys existing approaches and identifies commonly utilized methodologies, as well as existing eco-labeling programs and initiatives. In addition, we discuss the challenges of establishing a comprehensive and standardized index based on all the manufacturing aspects, since this will allow companies to quickly assess the environmental impact of their manufactured products. This exploratory paper also details possible approaches to alleviate shortcomings of current approaches. It is to be however noted that the paper is not exhaustive; an effort was made to include the most important/relevant ideas and the work was intended to be a good starting point for this research.

The remainder of this paper is organized as follows: Section 2 provides a literature review of current research on characterization of environmental, Section 3 provides information on prevalent eco-labeling programs and their symbologies and Section 4 discusses the challenges and opportunities for development of indexes for gauging sustainable manufacturing. Finally, Section 5 discusses the broader impacts of developing such an index.

2. Literature review

Current research (and literature) in the area of sustainable manufacturing can be divided into two mutually exclusive areas. Each broad area is briefly described below.

2.1. Environmental impact and product lifecycle evolution

The effect of human activity on the environment manifests itself as an "Environmental Impact", that is generally negative. A good definition is that used by Morón et al. (2009) who define environmental impact as "the difference between the future state of the modified environment, as it would be following project execution, and the future state of the environment as it would have evolved without such an action."

Though very common and accepted, this notion has never relied on precise metrics where relevant data can be assessed using standardized methodologies. The two major approaches to assessing the environmental/ecological impact are:

(a) Using quantitative data and metrics only, like measurements of gas emissions and amount of consumed energy, or
(b) Taking broader elements into account, including fuzzy qualitative parameters.

Most of the surveys conducted in industry belong to the first type. In the food industry, the focus is centered mainly on Greenhouse-effect gases emissions in the supply chain. The environmental impact is therefore generally simplified into "carbon footprint" as carbon dioxide is generally considered the most critical factor in androgenic climate change. The campaign financed by PepsiCo Inc. (Martin, 2009) is an illustrative example. Their brand Tropicana tracked the carbon emissions created to provide the final consumers with their orange juice. Another major retail group based in France (The Casino group), has moved a step further by adding a "carbon label" on their products package (Delahaye, 2008), (http://www.groupe-casino.fr/en/The-Casino–Carbon-Index-a-green.html). This label details the amount of greenhouse gases emitted to obtain the product, displaying it in CO_2-equivalent grams for 100 g of product. Such an initiative was however taken for the first time by the Walkers Crisps company in the UK, supported by the carbon trust (http://www.carbontrust.co.uk/Pages/Default.aspx). This was done by considering where the potatoes were grown, the manufacturing process, source of packaging, transport of the crisps to supermarkets and the impact of disposing off the empty packet once the crisps were eaten. Subsequently, energy consumption directly involved in each of these stages was calculated and suitably converted into resulting amount of carbon emissions and added to produce a final number. It may be noted that this effort highlighted inefficiencies in their manufacturing process which was subsequently altered to make it more efficient.

As indexes become more comprehensive, they also get more complicated and often include a large number of "difficult-to-quantify" parameters such as societal impact. In their work (Jawahir et al., 2006) develop a comprehensive index based on the design and manufacturing of a sample engineered product. This work integrates even societal elements, such as safety and health, in the developed product sustainability index (PSI). This is a new framework for comprehensively evaluating the sustainability content of a product throughout its entire lifecycle. The PSI is designed to capture the environmental impact of each product lifecycle phase. The method is useful in comparing various similar and competitive products. It should be noted that the product life cycle evolution in the context of its environmental impact is described later in this section.