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ANALYSIS

A waste input–output life-cycle cost analysis of the recycling of end-of-life electrical home appliances

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Abstract

However excellent a product may be environmentally, it would not come into wide use in the economy to realize its environmental load reducing potential unless it is also economically affordable. Life-cycle costing (LCC) is a tool to assess the cost of a product over its entire life cycle, and can be regarded as an economic counterpart of LCA. A combined use of LCA and LCC would be imperative for assessing the sustainability of a product or product systems in the economy. This paper presents a new methodology of LCC which gives the cost and price counterpart of the hybrid LCA tool (Waste Input–Output, WIO) that was developed by Nakamura and Kondo (2002) [Nakamura, S., Kondo, Y., 2002. Input–output analysis of waste management. Journal of Industrial Ecology 6 (1), 39–63.] for LCA of waste management. Building upon the preceding LCA study by Kondo and Nakamura (2004) [Kondo, Y., Nakamura, S., 2004. Evaluating alternative life-cycle strategies for electrical appliances by the waste input–output model. International Journal of Life Cycle Assessment 9 (4), 236–246.], the applicability of the methodology is illustrated by a case study of electric appliances under alternative end-of-life scenarios: landfilling, intensive recycling that is consistent with the Japanese law on the recycling of appliances, and an advanced form of intensive recycling augmented by Design for Disassembly (DfD). Application of the proposed LCC methodology indicates that while the life-cycle cost is the highest under intensive recycling and the lowest under landfilling, the cost of recycling can be reduced by appropriate implementation of DfD. The possible introduction of a carbon tax is also found to significantly reduce the cost disadvantage of recycling against landfilling. Given the high level of environmental load associated with landfilling and the possible introduction of carbon taxes, Design for Environment or EcoDesign emerges as a strategy of vital importance to achieve the sustainability of appliances.

Keywords: LCC; LCA; Electric appliances; Recycling; Design for Disassembly

1. Introduction

Life-cycle assessment (LCA) is a powerful tool to assess the environmental load of a product (Guinée, 2002). Its application would enable one to compare

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the environmental load of alternative products, and identify the one with the least load. However excellent a product is with regard to environmental load, however, its wide introduction into the economy would not follow unless it is also economically affordable. Without a wide-ranging introduction into the economy, its potential to reduce environmental load remains unexploited.

The aspect of cost is thus of great importance for assessing the economic affordability and hence the economic sustainability of a product which is found environmentally sound by an LCA. The aspect of cost that matters here, however, is not limited to the conventional one referring to that of manufacturing only, but should be a broader one referring to the life-cycle cost that encompasses the use and the end-of-life cost as well. Life-cycle costing (LCC) is concerned with the comparison of life-cycle costs among alternative product systems (Rebitzer, 2002; Norris, 2001).

With regard to the methodology of LCA, the hybrid use of input–output analysis (IOA) and detailed process modeling has increasingly become a standard (Matthews and Small, 2001; Suh et al., 2004). Along this line of research, Nakamura and Kondo (2002) proposed a new methodology, termed the waste input–output model (WIO), that is specially designed for an LCA of waste management. This paper is concerned with a new methodology of LCC, the WIO price model, which builds upon the cost- and price counterpart of the WIO quantity model. In IOA, it is well known that dual to any quantity system determining the quantity of flow of inputs and outputs for a given vector of final demand, there does exist a cost or price system that determines the cost per unit of production (and hence the price of output) for a given vector of the price of primary factors (Kurz and Salvadori, 1995; Miller and Blair, 1985). In conventional IOA, the derivation of a price system that is dual to a quantity system is straightforward. In WIO, however, that is not the case because of the presence of waste as joint products and the sale and purchase of waste materials, the value of which can be positive, zero, or negative.

Building upon the preceding LCA study by Kondo and Nakamura (2004), the applicability of the proposed LCC methodology is illustrated by a case study of electrical home appliances (EHA), TVs, refrigerators, washing machines, and air conditioners, under alternative end-of-life (EL) scenarios. These appliances were chosen because they are the objective of the Japanese home appliance recycling law that was put into effect in 2001 (METI, 2005). Three end-of-life scenarios are considered: landfilling, intensive recycling that is consistent with the recycling law, and intensive recycling augmented with implementation of Design for Disassembly (DfD) (for details of these scenarios, see Section 3.1). Our major concern in this study consists in the end-of-life phase: the costs related to the use phase are not considered. In other words, we consider the case where the performance of appliances is the same in the use phase.

According to Kondo and Nakamura (2004), landfilling is the treatment with the highest environmental load, and recycling with DfD the one with the least load, followed by recycling without DfD. In the first part of case study, we obtain the life-cycle cost (at the manufacturing and end-of-life phases) of appliances for each of these end-of-life scenarios, and evaluate their economic affordability under current institutional set-ups. In the current Japanese economy, the emission of CO_2 of fossil fuel origins itself does not involve any economic costs, and hence belongs to externalities, which need not be accounted for in LCC (Rebitzer and Hunkeler, 2003). If carbon taxes are to be introduced, however, the emission is internalized and needs to be accounted for in LCC. In the second part of the case study, the effects on the life-cycle costs of a carbon tax under alternative treatment scenarios are considered.

The paper is structured as follows. In Section 2 we start with a brief introduction to the WIO quantity model, derive its price counterpart, the WIO price model, and then implement it to the Japanese WIO table for 1995. Section 3 is devoted to the case study, where the WIO price model is adapted to the current literature on LCC, and applied to a LCC of electrical home appliances. The concluding remarks in Section 4 close the paper.

2. The WIO price model

2.1. Notations and basics

Let there be n^{I} goods- and service-producing sectors (henceforth "goods sector"), n^{II} waste treatment sec-