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Integrating life cycle costing and life cycle assessment using extended material flow cost accounting

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ABSTRACT

There is the undisputed need for the coupling of Life Cycle Costing (LCC) and Life Cycle Assessment (LCA) – the most common methods for the evaluation of the life cycle-wide economic and ecological effects of products and production systems in the context of sustainable decision making. However, in published studies both methods are often used in parallel or with little integration. This causes double work in data acquisition and a lack of consistency of the underlying analyses' scopes and, therefore, limits the significance of the analyses results. Further on, no mature theoretical approach for the integration of LCA and LCC exists. To overcome this problem, the paper presents a procedure model for the integrated use of the methods. More specifically, Material Flow Cost Accounting is suggested as a tie between both methods and is extended according to the requirements of life cycle-wide analyses.

1. Introduction

Integrated economic and ecological decision making is a subject of growing importance. Promising instruments for the modeling and calculation of the respective effects are Life Cycle Assessment (LCA) and Life Cycle Costing (LCC). Though 'an increasing number of studies show the interest of evaluating both Life Cycle Cost and Environmental Life Cycle performance in a consistent way' (Schwab Castella et al., 2009, p. 430), the LCA and LCC analyses are often done in parallel and on the basis of differing scopes, life cycle models, scenarios, and/or data bases (see, e.g., Lim and Park, 2007). This causes double work and a lack of consistency limiting the significance of the results. Pursuing the 'consistent way of evaluation' calls for a stronger integration of the approaches. In this regard, the paper first analyzes the goal-, data-, and method-related similarities of LCA and LCC. Afterward, the current state of LCA–LCC coupling is outlined and critically discussed (Section 2). The findings indicate the need for further methodical support for integrated LCC–LCA studies. To meet this need, a procedure model is presented structuring the necessary activities of an integrated study. Based on this, the relevant challenges and requirements of an integrated study are derived (Section 3). Thereafter, motivated by the existence of common methodical elements and the potential to provide additional insights, the approach of Material Flow Cost Accounting (MFCA) is suggested as a tie between LCC and LCA. The life cycle-related use of MFCA requires some extensions that are also introduced and discussed in Section 4. The paper finishes with a conclusion and an outlook (Section 5).

2. Life cycle-wide appraisal

For life cycle-related economic and ecological decision making, LCC and LCA are the two major approaches (see e.g., Helu et al., 2012; Klöpffer and Renner, 2008; Rebitzer, 2002; Rossi and Sinh, 2013). LCC is a cost management method for the evaluation of all economic consequences (e.g., costs, revenues, cash flows) and monetary trade-offs occurring in an object's life cycle (Brown and Yanuck, 1985). It contributes to cost-oriented decision making concerning multiple life cycle phases and can be applied for cost driver identification, profitability assessment as well as for product and production technology design and strategy comparisons, etc. (for further applications see Dhillon, 1989; DIN, 2005). In contrast, LCA focuses on revealing the life cycle-related environmental burdens of a product system (including the related processes and resources) by systematical identification and quantification of its ecological impacts. As a procedure for assessing the environmental burdens and benefits of a product system, it supports the development of ecologically intended improvement measures and, thus, the design of eco-friendly products and production processes (ISO, 2006a).

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Though LCC and LCA are both used for life cycle-wide appraisals and even refer to the same types of objects (products, processes, resources), they are often applied independent of each other (Norris, 2001). This might result from the differing underlying intentions and the specific methods for the calculation of the related economic or ecological target figures. However, there are several *similarities* arguing for an integration of the concepts:

(1) Some similarities get visible when comparing the *overall goals* pursued by the application of LCC and LCA. They can be classified according to the goal categories known from traditional cost accounting (see Schweitzer and Küpper, 2011). By providing a comprehensive basis of information about a product's life cycle, both approaches contribute to the *documentation* of product-related business processes and their effects. Especially in LCA, documentation is one of the main purposes providing the basis for sustainability reporting and eco-labeling (ISO, 2006a). Beyond that, the information generated in LCC and LCA studies supports priority setting and long-range *planning*. LCC facilitates decision making for product and process design, equipment acquisition and replacement (e.g., new technologies, aging facilities) as well as capital allocation (e.g., competing projects), budgeting, etc. Similarly, LCA – as already mentioned – supports the design of environmentally acceptable products and processes. So, LCC as well as LCA contribute to identifying favorable alternatives. When applying LCC and LCA regularly, they also serve as instruments to *control* business performance, for instance by analyzing the economic and ecological success (or failure) of measures (e.g., achieving cost or emission targets). Besides, both aim at raising awareness – either for economic or for ecological impacts and interrelations – and, hence, intend some sort of *behavioral control*. Concluding, it can be stated that the overall goals pursued by LCC and LCA are largely the same. What differs is primarily the addressed dimension – which is an economic one for LCC and an ecological one for LCA. Economic and ecological goals may be competing, neutral, or complementary. So, in general, an integrated use of LCA and LCC could be essential for identifying trade-offs between both goal dimensions, finding the ecologically *and* economically best decision alternative, and might in particular help to realize ecologically intended measures. It is typically necessary to justify the capital investment caused by such measures. In some cases, this could be facilitated by assessing the relevant economic consequences throughout the life cycle appropriately and, thus, taking potential differences in follow-up costs into account (Shapiro, 2001).

(2) Basic elements of LCC and LCA are *system modeling* (including the setting of system boundaries) and establishing an appropriate *data base*. Fundamental parts of system modeling in LCC as well as in LCA are subdividing the life cycle into relevant phases and decomposing the product system (often with the help of product and process breakdown structures). The resulting models form the basis for data collection. Here, process in- and outputs, technology descriptions (production principles, equipment and machinery used, etc.) as well as the impacts of influencing factors over time are essential information for a comprehensive evaluation of both the economic and the ecological efficiency (Baumann and Tillman, 2004; DIN, 2005; ISO, 2006a). Consequently, the modeled system structures and the required data base are quite similar (for similarities between LCC and LCA data see e.g., Rebitzer, 2005). An integrated use of LCC and LCA may help to realize synergy effects and, as a result, to reduce efforts for modeling and/or data collection. This is especially relevant since system modeling, data acquisition and data analysis are typically the most time consuming activities in LCC and LCA studies.

(3) Further similarities concern the applicable *methods*. In each case, a variety of factors influencing a product system's performance has to be regarded. In order to consider these factors appropriately, usually one or more scenarios are built and analyzed. Here, scenario analysis (see Schnaars, 1987), system-analytical methods (e.g., MICMAC-method (see Godet, 1986)), and system dynamics (see Richmond, 1994) may be applied for LCC as well as for LCA. The same holds true for methods of modeling and recording the inputs and outputs of processes and other system elements (e.g., input–output analysis, flow models and diagrams). Additionally, both concepts face the problem that the product system to be evaluated is embedded in a complex production environment and shares many of the resources with other products (e.g., facilities, equipment, energy). Therefore, most of the costs as well as ecological burdens cannot be allocated to the products using the causer-pays-principle. According to ISO (2006b), the allocation of ecological burdens should (i) be avoided (by dividing unit processes or expanding the product system), (ii) be based on physical relationships or (iii) be done in proportion to economic figures. Similarly, for LCC it is suggested to either renounce the assignment of the costs of shared resources (Back-Hock, 1988, referring to the 'Einzelkosten-und Deckungsbeitragsrechnung' by Riebel (1994)) or to use significant reference figures as allocation criteria (Zehbold, 1996, based on the 'Grenzplankostenrechnung' (Kilger et al., 2002)). These quite sophisticated allocation rules can also be transferred to LCA. Compared to a parallel use of both concepts, the application of the same methods and a shared data base (2) would contribute to a common definition of underlying assumptions and, consequently, to form a consistent basis for the final decision making.

Recognizing these potentials, first approaches and studies evaluating the life cycle-related ecological as well as economic consequences of objects do already exist. They can be categorized in three groups. The first category refers to the (widely) *parallel application* of both approaches. Here, in a first sub-group LCA and LCC are conducted separately, each with its own goal and scope definition, life cycle concept, and data base (see Lim and Park, 2007). The approach of eco-efficiency analysis forms a second sub-group (Huppes and Ishikawa, 2005; Kicherer et al., 2007). It is characterized by a common definition of system boundaries and time-scales and the joint evaluation of the LCC and LCA results. Further steps of the LCC and the LCA analysis (definition of evaluation concepts and methods, data compilation and forecast, etc.) are conducted independent of each other. When applying (major parts of) LCC and LCA in parallel, the results are (widely) based on different system models and assumptions – reducing the significance and the quality of decision making. Additionally, synergy effects concerning data acquisition are limited.

The second category integrates *cost aspects in LCA* studies. In a first type of studies, a separate economic impact category representing the cost impacts is defined in addition to the ecological ones (see Ferguson et al., 2005). A specific method following this strategy by using LCA flow models for a cost–benefit analysis is the 'material flow analysis' (MFA) (see e.g., Brunner and Rechberger, 2004). The monetary figures generated in this type of studies may serve as a means for the economic analysis and interpretation of the ecological impacts. Unfortunately, most of the studies do not