Journal of Cleaner Production xxx (2016) 1–9

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

The importance of including secondary effects when defining the system boundary with life cycle perspective: Case study for design of an external wall

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ARTICLE INFO

Article history:
Received 28 January 2016
Received in revised form
29 November 2016
Accepted 3 December 2016
Available online xxx

Keywords:
Life cycle assessment
Life cycle cost assessment
System boundary
Building
External wall
Global warming

ABSTRACT

Life cycle assessment and life cycle cost analysis are suitable tools in trying to minimize environmental impact and cost. To get reliable results it is crucial to set up correct system boundaries for the investigation, but it is often difficult to understand a complex products system because of the cascade effects of consequences that can be induced even by small changes. In this paper the effects and consequences evaluation (ECE) method is introduced to systematically identify and organize the effects and consequences for a design change of parts of a complex system. The method is applied in a case study of external wall insulation for a new building to investigate the importance of correct system boundaries. Using the methodical approach in identifying all significant consequences showed that unexpected unit processes can be important when deciding on the relevant system boundary. We also conclude that such processes can have a significant impact on the final results by calculating the change in global warming potential and life cycle cost for the processes affected by the design option.

1. Introduction

Defining goal and scope is crucial in life cycle assessments. There are no standalone life cycle assessment results, as the findings always depend on the questions, assumptions and limitations stated in the goal and scope of the assessment. Goal and scope include (i) defining the functional unit; (ii) choice of impact parameters and impact assessment method; (iii) natural, geographical, temporal and technical system boundaries; and (iv) data quality (Swedish Standards Institute, 2006). These issues will be different in attributional or change-oriented assessments. The attributional life cycle assessment describes physical flows to and from a life cycle during set (static) conditions. The change-oriented life cycle assessment describes how these physical flows will change due to alterations made in the life cycle. The change-oriented approach often goes beyond the life cycle under consideration by avoiding allocations and instead utilizes system expansion (Ekvall and Weidema, 2004). In addition, it can be practical in a change-oriented assessment to divide the investigated system into a foreground system, that includes processes where changes through active choices can be applied, and a background system with the processes that are implicitly affected by the foreground processes (Baumann and Tillman, 2012, p 88–90). Dividing the system into these two groups will create a better understanding and facilitate the investigative work.

Decreasing energy use in buildings has been a high priority for several years. Recently, this has become even more important with the recent requirement for nearly zero energy buildings from the Energy Performance of Buildings Directive (European Parliament, Council of the European Union, 2010). A common measure used to decrease operational energy is to reduce heating losses by adding insulation. However, when more materials are used the environmental impact from production and materials increases compared to operational energy. Studies have shown that the environmental impact from the materials and production for low energy buildings has a magnitude similar to the energy use during the entire

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http://dx.doi.org/10.1016/j.jclepro.2016.12.009
0959-6526/© 2016 Published by Elsevier Ltd.

operation phase (Thormark, 2002; Liljenström et al., 2014). This change has led to a shift of interest, from mere energy saving measures, to making life cycle assessments for buildings to include the impact from materials and production as well.

The development of methodologies to define system boundaries has been treated in other research, albeit not, to our knowledge, specifically concerning buildings. For accounting life cycle assessments there are product category rules (PCR) that define the goal and scope for whole buildings and building products (International EPD System, 2014). On the other hand, less work has been conducted concerning change-oriented life cycle assessments on buildings. A key to correctly evaluating which unit processes to include in the system is knowing which relevant ones are available for consideration. This might be difficult to appraise as different parts of a product's production and use phases often have complex relationships. A building has, for instance, many products and services that are mutually dependent and therefore can be connected in several different ways, like fire safety, weight load and thermal insulation. Tillman et al. (1994) describes how to address the issue of system boundaries on a generic level for products by giving general guidelines and principles to be applied in any life cycle assessment. Ekvall and Weidema (2004) further address how to reason when deciding on the boundaries in general for change-oriented life cycle inventories. Studies have also been conducted on how to define the system boundary by excluding insignificant unit processes; Li et al. (2014) presented a method for this kind of exclusion by introducing a delimitation method. However, the method has not been evaluated for comparative life cycle assessments. The Relative Mass-Energy-Economic (RMEE) method provides a means to evaluate the significance of unit processes compared to the complete system (Raynolds et al., 2000). RMEE targets life cycle assessments of energy and products, where the focus is on typical combustion-related air emission, but the reasoning of Raynolds et al. (2000) can be useful in deciding on relevant unit processes for buildings as well.

When designing a building, minimizing its environmental impact is desirable, and this can be evaluated with change-oriented assessments, as it is of interest to explore how a change in design might lower environmental impact at a reasonable cost. The economic aspect can be evaluated through life cycle cost calculations, and although life cycle cost and environmental calculations are fundamentally different it is possible to combine them. Such combinations have been made, for example, by Verbeeck and Hens (2007), Gu et al. (2008) and Tatari and Kucukvar (2012). Though the methods can be useful, these kinds of studies are often performed as screening life cycle investigations with no detailed description of how to set up the goal and scope. For a fair evaluation of different design options it is essential that the goal and scope, of which system boundary is an important aspect, is established in a correct and consistent way.

This has to be considered when carrying out optimization studies. In optimizations one or several variables are varied to find an optimum, or several optima, within set conditions. The system boundary will establish the dependencies between the parameters in the optimization. If the dependencies are not carefully studied there is a risk that when a variable is varied, other variables that are dependent of the varied variable will not in turn be altered correctly, or wrongly considered constant. This can have the implication that variable sets which are not valid for the investigated system are used, leading to incorrect results.

Previous studies implicitly assume that all relevant processes are identified when their method is carried out, or will be during the life cycle inventory. Thus, they do not present a methodology to first identify all unit processes that have to be included. This might lead to a goal and scope formulated in such way that relevant consequences fall outside of the life cycle assessment and will never be considered, even though these might have a significant impact on the environment and costs.

In Sweden the design process of a building commonly consists of many actors with their specific area of expertise, for example, architect that is responsible for the layout and geometry of the building, structural engineer for the loads, electrical specialist, environmental specialist and installation specialist. For each design option in a building they will provide information and solution within their own field, but they usually have only rudimentary knowledge of the other fields. This situation is likely similar to many other complex production systems. This means it is difficult to appraise the total extent of measures to be taken when a change that spans over several fields is implemented in such a system.

In this paper we examine the goal and scope when optimizing the building envelope regarding environmental and economic impact. The main purpose of the study is to show that seemingly simple changes in design of complex systems as, for example, increasing the insulation thickness in an external wall will lead to cascading effects well beyond the actual design choice by itself and have larger impact than can be expected intuitively. Although it would seem obvious that the initial change might affect other parts of the building, it is a very difficult task for a design team to tell exactly how the other parts are affected and to which magnitude. It is likely even more difficult for a life cycle assessment practitioner without deeper knowledge in building physics and the building design. The reason for this is that traditionally in Sweden the design team is supposed to solve the specification set by the developer, not evaluate the impact the solution has on the building life cycle. This means that there is a risk that the practitioner will unintentionally leave out important aspects if he or she does not question the design team and structure the information given in a systematic way. The effect and consequences evaluation (ECE) method is presented in this paper as a way to perform this structured approach to minimize the risk of neglecting important aspects and to structure the found information. More precisely, we investigate how aspects such as the size of roof, floor and energy use are affected by changes in the thickness of external wall insulation. A first step is to identify which significant processes or elements should be considered when performing life cycle evaluation for building design. This is done by looking at an example with light-weight stud walls, in which different thicknesses of external insulation are examined.

2. Method

To determine possible system boundaries the ECE was developed. In this method the possible effects of a design option are identified. For each effect the possible consequences are then determined. The procedure is repeated until all correlated consequences and effects are found. Each unit process in the obtained system can then be kept or removed based on a cut-off criteria. Instances might occur where several competing consequences are identified. That means there is a choice to be made and the unit process is then to be placed in the foreground system. Ideally, all diversities would be modeled as different scenarios, but for practical reasons, e.g., lack of resources, it may not always be feasible to assess all possible choices. Some options might then be left out if doing so is consistent with the goal and scope of the study. Typical effects that can be applicable for a building include changes in volume, surface area, weight, energy, power, cost, construction time, moisture risks, fire safety, indoor environment, acoustics, accessibility for disabled people, security and stormwater management. These can be further divided or grouped together. For example, energy could be split into heat transmission, heat storage