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Life cycle assessment of capital goods in waste management systems

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ABSTRACT

The environmental importance of capital goods (trucks, buildings, equipment, etc.) was quantified by LCA modelling 1 tonne of waste treated in five different waste management scenarios. The scenarios involved a 240 L collection bin, a 16 m^3 collection truck, a composting plant, an anaerobic digestion plant, an incinerator and a landfill site. The contribution of capital goods to the overall environmental aspects of managing the waste was significant but varied greatly depending on the technology and the impact category: Global Warming: 1–17%, Stratospheric Ozone Depletion: 2–90%, Ionising Radiation, Human Health: 2–91%, Photochemical Ozone Formation: 2–56%, Freshwater Eutrophication: 0.05–99%, Marine Eutrophication: 0.03–8%, Terrestrial Acidification: 2–13%, Terrestrial Eutrophication: 1–8%, Particulate Matter: 11–26%, Human Toxicity, Cancer Effect: 10–92%, Human Toxicity, non-Cancer Effect: 1–71%, Freshwater Ecotoxicity: 3–58%. Depletion of Abiotic Resources – Fossil: 1–31% and Depletion of Abiotic Resources – Elements (Reserve base): 74–99%. The single most important contribution by capital goods was made by the high use of steel. Environmental impacts from capital goods are more significant for treatment facilities than for the collection and transportation of waste and for the landfilling of waste. It is concluded that the environmental impacts of capital goods should always be included in the LCA modelling of waste management, unless the only impact category considered is Global Warming.

1. Introduction

Environmental impacts from waste management systems have been evaluated many times by life cycle assessment (LCA) during the last few decades. However, in most studies the environmental costs of capital goods (buildings, machinery, etc.) have not been included. Frischknecht et al. (2007) used data from the Ecoinvent database (Ecoinvent, 2015), including capital goods for landfilling and incineration, and found that capital goods contributed significantly to the impact categories related to resource use (Mineral Resources and Land Use).

A few studies (Doka, 2009; Ecobalance, 1999; Ménard et al., 2004; Schleiss, 1999; Martínez-Blanco et al., 2010; Rives et al., 2010) have presented life cycle inventories for capital goods for single waste management technologies. In most cases the data were not well-documented, though, and so it is difficult to identify what is actually included. In recent studies we have provided details about capital goods for a range of waste management technologies: waste collection and transport (Brogaard and Christensen, 2012), landfills (Brogaard et al., 2013a), incineration (Brogaard et al., 2013b) and composting and anaerobic digestion (Brogaard et al., 2015). The mentioned studies demonstrated that some materials are used in large amounts per tonne of waste treated, but it is not always the case that the production of these materials has a major environmental impact. Materials used in smaller amounts can have the greatest impacts per tonne of material from production. In the present study the waste management of capital goods will also be included, i.e. impacts caused by the treatment of the waste capital goods as well as savings made by substituting virgin materials.

The objective of this study is to assess the importance of capital goods in waste management LCA studies, by using the recently published data described above. LCA modelling includes the materials and energy used in the construction of capital goods, the actual waste treatment, including recovered materials and energy, and some capital goods being recycled at the end of their life. The goal is to provide a quantitative assessment of the need and importance of including capital goods in future LCA studies of waste management systems.

2. Approach and method

The LCA modelling in this paper has two flow systems: a capital goods flow system and a waste flow system. This is illustrated in Fig. 1. The assessment of the capital goods system includes all life

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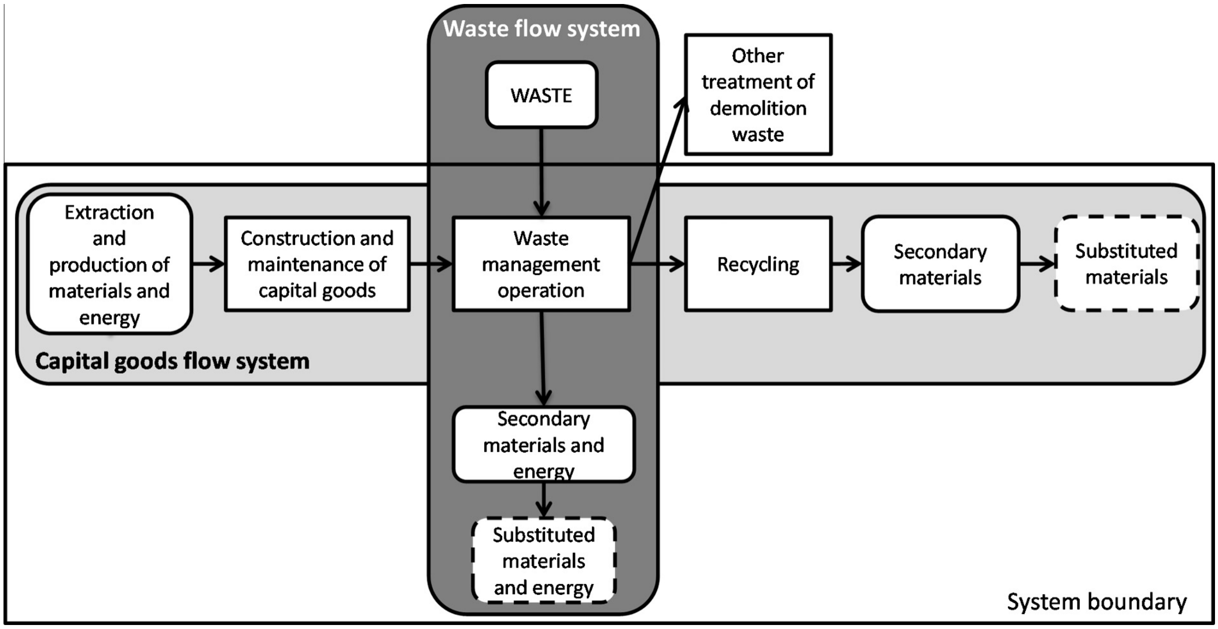

Fig. 1. Flow diagrams of the LCA and the system boundary. Dark grey area shows the waste flow system, also described as traditional boundaries for traditional waste management LCAs. Light grey area indicates the capital goods flow system. Secondary materials and energy are connected to the substituted production of materials and energy.

cycle phases: the extraction and production of materials and energy, the construction of capital goods in terms of plants and machinery, the maintenance of capital goods during use and their disposal, where they are recycled or subjected to other treatments. Transportation is included in the processes and between the life cycle phases. Capital goods data provided by Brogaard and Christensen (2012) and Brogaard et al. (2013a, 2013b, 2015) were expressed per tonne of waste treated, and the operational capacity, maintenance and lifetime of the various components of capital goods were taken into account. The waste management of such materials is included in the present assessments. Life cycle inventory data for the production of materials and energy for capital goods and all process data were obtained from relevant sources. References for all processes are presented in the Supporting Information Table S7.

The waste system considers waste as a "zero-burden" boundary, which means that the production of products and materials that end up as waste is not included in the LCA modelling. The products were produced and used for a purpose other than merely becoming waste. The waste system includes the collection and transportation of waste, the treatment of waste and the materials and energy recovered. Recovery creates environmental savings, as the waste management system is credited with environmental loads avoided by not producing materials and energy via virgin sources.

2.1. Conceptual model

The standard conceptual model for waste management system LCAs consists of potential environmental impacts (PEIs), which is equal to the impacts of handling of one tonne of waste, including the recovery of materials and energy (W). In the following the introduction of capital goods (CG) to the waste management system LCA will be presented. In order for the LCA to be comprehensive, potential environmental impacts from the total waste management system per tonne of waste handled (PEI) equate to the sum of the impacts of the two flow systems (CG and W). All the following considerations are per tonne of waste handled:

$$\mathrm{PEI} = \mathrm{CG} + \mathrm{W} \tag{1}$$

where

- PEI: potential environmental impact of the total waste management system per tonne of waste handled
- CG: impact made by capital goods used to handle one tonne of waste
- W: impact made by the handling of one tonne of waste, including recovery.

The waste system can be further decomposed:

$$\mathrm{W} = \mathrm{C_w} + \mathrm{T_w} - \mathrm{m_w} \cdot \mathrm{SM} - \mathrm{e_w} \cdot \mathrm{SE} \tag{2}$$

where

- C_w: impact made by the collection and transport of one tonne of waste
- T_w: impact made by the treatment of one tonne of waste
- SM: impact made by saved materials, expressed as the impact made by similar production processes using virgin materials
- m_w: a factor expressing the amount of virgin material production avoided per tonne of waste handled. This factor is affected by technical and mechanical material losses.
- SE: impact made by saved energy, expressed as the impact of similar energy production processes using other energy sources
- e_w: a factor expressing the avoided amount of energy produced per tonne of waste handled.

The capital goods system can be further decomposed; the parenthesis represents the disposal phase of capital goods:

$$\mathrm{CG} = \mathrm{E_{CG}} + \mathrm{C_{CG}} + (\mathrm{R_{CG}} + \mathrm{L_{CG}} + \mathrm{I_{CG}} - \mathrm{m} \cdot \mathrm{SM_{R,I}} - \mathrm{e} \cdot \mathrm{SE_{I,L}}) \tag{3}$$

where

- E_{CG}: impact made by material extraction and production (including maintenance and lifetime considerations) per tonne of waste handled