Waste Management 48 (2016) 565–583

Contents lists available at ScienceDirect

Waste Management

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

Comparison of different methods to include recycling in LCAs of aluminium cans and disposable polystyrene cups

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ARTICLE INFO

Article history:
Received 24 February 2015
Revised 24 August 2015
Accepted 21 September 2015
Available online 3 October 2015

Keywords:
Life cycle assessment (LCA)
Recycling
Allocation
Aluminium
Polystyrene

ABSTRACT

Many methods have been reported and used to include recycling in life cycle assessments (LCAs). This paper evaluates six widely used methods: three substitution methods (i.e. substitution based on equal quality, a correction factor, and alternative material), allocation based on the number of recycling loops, the recycled-content method, and the equal-share method. These six methods were first compared, with an assumed hypothetical 100% recycling rate, for an aluminium can and a disposable polystyrene (PS) cup. The substitution and recycled-content method were next applied with actual rates for recycling, incineration and landfilling for both product systems in selected countries.

The six methods differ in their approaches to credit recycling. The three substitution methods stimulate the recyclability of the product and assign credits for the obtained recycled material. The choice to either apply a correction factor, or to account for alternative substituted material has a considerable influence on the LCA results, and is debatable. Nevertheless, we prefer incorporating quality reduction of the recycled material by either a correction factor or an alternative substituted material over simply ignoring quality loss. The allocation-on-number-of-recycling-loops method focusses on the life expectancy of material itself, rather than on a specific separate product. The recycled-content method stimulates the use of recycled material, i.e. credits the use of recycled material in products and ignores the recyclability of the products. The equal-share method is a compromise between the substitution methods and the recycled-content method.

The results for the aluminium can follow the underlying philosophies of the methods. The results for the PS cup are additionally influenced by the correction factor or credits for the alternative material accounting for the drop in PS quality, the waste treatment management (recycling rate, incineration rate, landfilling rate), and the source of avoided electricity in case of waste incineration. The results for the PS cup, which are less dominated by production of virgin material than aluminium can, furthermore depend on the environmental impact categories. This stresses the importance to consider other impact categories besides the most commonly used global warming impact.

The multitude of available methods complicates the choice of an appropriate method for the LCA practitioner. New guidelines keep appearing and industries also suggest their own preferred method. Unambiguous ISO guidelines, particularly related to sensitivity analysis, would be a great step forward in making more robust LCAs.

1. Introduction

Recycling is a well-known and widely used waste treatment to valorise the properties of wasted materials or products. The Waste Framework Directive of the European Commission prioritizes recycling in the waste management hierarchy over energy recovery and disposal options that do not include any kind of recovery (e.g. landfilling, incineration without energy recovery, emission to water bodies) (European Commission, 2008).

Recycling retains wasted materials or products by converting them into secondary materials. These secondary materials typically replace new materials and thus conserve resources. The four main recycled materials in Europe are glass, metals, paper and cardboard, and plastics (European Environment Agency, 2012).

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http://dx.doi.org/10.1016/j.wasman.2015.09.027
0956-053X/

Recycling rates, i.e. the degree to which a product or material enters recycling, can vary among products which are made from the same material. The European recycling rate for all steel for example is 85% on average, but it is 70% for steel packaging and 99% for scrap cars (TATA Steel, 2014).

The environmental and economic benefits of recycling depend on the recycling process itself, the avoided production of new material, and the market for the recycled material. Recycling is profitable from an economic perspective if the profits from the recycled material outweigh the recycling process costs. The environmental benefits of recycling can similarly be positive if the environmental credits from the recycled material outweigh the environmental burdens of the recycling process. Quantifying the benefits of recycling in the environmental assessment of products, i.e. by life cycle assessment (LCA) (ISO 14040 (ISO, 2006a)), is unfortunately not straightforward due to the ambiguous character of the recycling process.

The recycling process cannot only be considered as a waste management process, but also as a production process for material. The recycling process is thus shared between two product systems, one producing the recycled material and one using the recycled material. This makes the recycling process to what in LCA is called a multi-functional process. It is for multi-functional processes not obvious to which product system the environmental impacts of that multi-functional process should be attributed (Finnveden and Potting, 2014).

Recycled material may be used to produce the same product as the one from which the recycled material originates. This leads to a so-called closed-loop recycling system. The properties of the recycled material need to be identical to those of the original material in this case. The recycled material does not physically need to enter the same product system, but instead it is added to the stock of material with the same quality as the virgin material. Metals (e.g. steel, aluminium, copper, zinc) are examples of materials maintaining their quality and properties in the recycling process (Atherton, 2007). The quality of the metal may degrade, however, due to the inclusion of impurities, although the properties of the metal itself do not change during the recycling process. Metals are often mentioned as examples of closed-loop recycling systems, although this assumption might not be correct.

Material can also degrade during the recycling process, leading to an open-loop recycling system in which the recycled material can only replace virgin material with a lower quality or a totally other material in the next product. The length of paper fibres, for example, is shortened during the recycling process. This gives recycled paper fibres a lower quality compared to fibres from virgin wood, although recycled paper fibres are still an excellent source for paper and board production (Merrild et al., 2008). Plastics can degrade during the recycling process, due to shortening of the polymer chains and heterogeneity of the material (Al-Salem et al., 2009), applied additives, and plain contamination during the use of plastic products. A quality drop in the recycled material reduces the application options of the recycled material, typically leading to down-cycling.

Different methods are practiced in LCA to assign the environmental impacts of the recycling process and the environmental benefits of the recycled material to the product system producing the recycled material and the product system using the recycled material (e.g. Ekvall and Finnveden (2001), Ekvall and Tillman (1997), EC-JRC (2010), Guinée et al. (2002), Ligthart and Ansems (2012), Newell and Field (1998)). These methods can result in different LCA outcomes for the same product system (Azapagic and Clift, 1999; Cederstrand et al., 2014; Ekvall and Finnveden, 2001; Liu and Müller, 2012; van der Harst et al., 2014; Wardenaar et al., 2012; Weidema and Schmidt, 2010). This discrepancy in outcomes is not beneficial for the credibility and reliability of LCA studies and its use as a decision support tool.

This paper addresses three questions on the assessment of recycling in LCA. A first and main question is how and where, i.e. to which product system, to assign the environmental impacts of the recycling process and the environmental benefits of recycled material to the different product systems. This so-called 'allocation problem' is one of the most debated and controversial issues in LCA (Ekvall and Finnveden, 2001; Finnveden et al., 2009; LCA Forum, 2007; PRé Consultants, 2011; 2013; Reap et al., 2008; Weidema, 2003). Any loss in quality of the recycled material also needs to be accounted for in LCA, because the functionality of the recycled material is not the same as the original material. A second question in LCA is, therefore, how to account for loss in quality of the recycled material. Recycling methods are applied in real product systems and their actual waste treatment options. Different methods can lead to different LCA outcomes. There might be, on the other hand, additional aspects affecting the LCA results for recycling. The third question is, therefore, how sensitive LCAs results are for the choice of recycling methods compared to other factors in the recycling process.

This paper evaluates six widely used methods for modelling recycling in LCA: (1) *substitution-with-equal-quality*, (2) *substitution-with-correction-factor*, (3) *substitution-with-alternative-material*, (4) *allocation-on-number-of-recycling-loops*, (5) *recycled-content method*, and (6) *the equal-share method*. Each model is first described and then applied to two case studies: (1) an aluminium can, and (2) a disposable polystyrene (PS) cup. Next, these six methods are discussed in relation to their underlying philosophies and their influence on the case study results. Finally, one of the *substitution* methods and the *recycled-content* method are again applied to the two case studies, but now reflecting different waste management practices in several European countries.

2. Methods

2.1. Life cycle assessment (LCA)

Life cycle assessment (LCA) is a standardised method to assess the environmental performance of products or service systems (ISO, 2006a). An LCA consists of four methodological phases: (1) goal and scope definition, (2) inventory analysis, (3) impact assessment, and (4) interpretation. The goal of an LCA describes the purpose of the study and the targeted audience. The scope sets the methodological framework for the study and therewith defines how the other methodological phases are performed. The scope includes amongst others the definition of a functional unit, i.e. the function of the product under examination, and the system boundaries of the investigated product system. Also the handling of multi-functional processes in inventory analysis is laid down in the scope definition. Inventory analysis consists of the collection and processing of data about the environmental inputs (e.g. natural resources) and outputs (emissions, waste, products) for all included life cycle processes. These data are used in the impact assessment phase to calculate the contribution of the product system to a range of environmental impacts. The interpretation phase evaluates the results from the inventory analysis and impact assessment, and makes conclusions based on the goal and scope definition.

2.2. Research approach

This paper evaluates six methods for handling recycling in LCA and applies them on two case studies: (1) an aluminium can, and