End-of-life best approach for allocating recycling benefits in LCAs of metal packaging

Report
Delft, February 2013

Author(s):
Geert Bergsma
Maartje Sevenster

Publication Data

Bibliographical data:
Geert Bergsma, Maartje Sevenster
End-of-life best approach for allocating recycling benefits in LCAs of metal packaging
Delft, CE Delft, February 2013

Packaging / Metals / Recycling / Production / LCA
FT : Allocation / End-of-life

Publication number: 13.8231.02

CE-publications are available from www.cedelft.eu

Commissioned by: Stichting Kringloop Blik.
Further information on this study can be obtained from the contact person Geert Bergsma.

CE Delft
Committed to the Environment

CE Delft is an independent research and consultancy organisation specialised in developing structural and innovative solutions to environmental problems.
CE Delft's solutions are characterised in being politically feasible, technologically sound, economically prudent and socially equitable.

Contents

Summary

In life cycle assessments (LCA) that involve recycling of materials, one has to choose a method for allocation of processes and avoided emissions that fits the goal and scope definition of the assessment. There are two main approaches to recycling:

- End-of-life (EOL) recycling approach (also known as avoided burden). Environmental benefits are only granted for the fraction of material that is recovered and recycled after the use phase.
- Recycled content (RC) approach (also known as cut off). Environmental benefits are only granted for the actual fraction of secondary material in a product.

The choice of allocation has a major influence on the results of the LCA for a particular product. The choice is a value choice, i.e. there are no guidelines from natural science. In this report, several arguments that point to one of the two approaches are discussed and applied to the case of metal packaging.

There are good reasons to prefer an EOL approach to metal as packaging material, from the perspective of promoting recycling and rewarding recycling efforts:

- there is no quality loss, so no effort required to apply secondary metals;
- the demand for secondary material is high and will be high in the foreseeable future;
- metal packaging has a short life span, thus it is certain that the secondary metarial provided will be used.;

In some redefined protocols, a recycled content approach may be dictated.
It is argued that in the current market structure of secondary metals, boosting recycled content does not lead to avoided virgin production. For metal packaging, it would be better to interpret the EOL recycling rate as an adequate substitution for the 'recycled content' approach in such contexts as long as this recycling rate is guaranteed.

At the level of installations, forcing higher recycled content may be neither technically feasible nor desirable from an environmental perspective as long as the global demand for metals is much higher than the supply of scrap metals.

In relation to the carbon footprint of metal packaging we conclude that the recycling performance should be determined by the end-of-life recycling figure (e.g. 85% in the Netherlands).

1 Introduction

1.1 Background and goal

In life cycle assessment (LCA) according to ISO 14040/44, the practitioner has to choose a method for allocation that fits the goal and scope definition of the assessment. Allocation is needed in several situations. One of those is recycling of end-of-life materials. There are essentially two approaches to recycling (e.g. Frischknecht, 2010):

- recycled content approach (also known as cut off);
- end-of-life recycling approach (also known avoided burden).

The choice of allocation has often a major influence on the results of the LCA for a particular product (see Annex A). Therefore, some sectors and/or product groups are defining preferred standards for dealing with recycling in LCA. Amongst others, the global metals industry has made a ‘Declaration by the Metals Industry on Recycling Principles’, published in the International Journal on LCA (Atherton, 2007).

This declaration states the following:
“*For purposes of environmental modelling, decision-making, and policy discussions involving recycling of metals, the metals industry strongly supports the end-of-life recycling approach over the recycled content approach.*”

In this report, the considerations underlying this choice and its practical consequences are discussed.
The focus of this report is the allocation choice for metal packaging.

1.2 Approach

In order to understand the choice of recycling approach fully, it is necessary to look at the subject from several perspectives. LCA practitioners are dealing with several standards that may prescribe certain methodological choices and thus may be faced with contradictory guidelines. As the choice of recycling approach is a value choice (e.g. Frischknecht, 2010) it is not simply a matter of natural sciences. Considerations such as promotion of the collection of secondary materials or the precautionary principle come into play, as well as question of fairness (who pays for recycling and who gets benefits?).

We therefore pay attention to such perspectives by structuring the report around the following questions:

- What are the approaches to model recycling in LCA (Annex A)?
- Which considerations should guide the choice of approach?
- What are consequences of the choice of approach?
- What conclusions may be drawn and what are recommendations for LCA practitioners?
- How relate both systems with each other?

In this report, the discussion of recycling is somewhat simplified for sake of clarity. Recycling is meant to indicate all material recovery, also from incineration slags as is possible uniquely for metals.

2 Allocation of recycling benefits for metal packaging

2.1 Promoting collection or application?

From a societal perspective, increasing recycling in general is considered desirable. One perspective in the choice of modelling approach is therefore to assess which approach is aligned with stimulating recycling overall.

For different materials, different stimuli may be required to increase the overall effective recycling. Two important aspects are quality loss and the need for design for recyclability. For materials with low quality loss, the use of secondary materials is in practice attractive as this is typically (effectively) cheaper than the use of virgin materials.

This is the case for metals and glass (see Table 1). For glass, energy use is considerably lower in the case of recycled materials than when using primary inputs (sand). Also, transport is less costly. For steel, the use of (some) scrap in a steelmaking furnace has several advantages (e.g. skipping the first production step: from ore to pig iron).

Table 1 **Recycling aspects of materials**

Material	Quality loss	Embodied in product	Recovery after MSWI	Issues
Metals	Zero	Mixed	Yes	Contamination
Glass	Zero	Mono	No	Colours
Paper	Some	Mono	No	Fibre length
Plastics	High	Mixed/mono	No	Packaging: contamination and different types of plastics
Wood	Varied	Mono	No	Contamination
Building materials (stone, cement based)	High	Mixed	N/A	Long product life

One could therefore argue, as is done in the Declaration of the Metals Industry (Atherton, 2007) that it is EOL collection that needs to be stimulated. Once secondary materials are available they will be used because the user does not experience any difference (they are also cheaper).

For glass, the collection rate is already high, as the material is contained in essentially mono-material products and collection and recycling is easy.
For some metal applications, this is not always the case, but for metal packaging the situation is like glass. Thus, for metals in general, design for recyclability is important to increase recyclability but for packaging this is no issue.

On the other hand, metals can be recovered after incineration, which decreases the need for disassembly and collection.

We can conclude that for metal packaging the end-of-life stage is determining the recycling performance.

2.2 Supply and demand

Considerations of supply and demand may also play a role in choosing a recycling approach. For metals, supply is typically much lower than demand. Supply is limited due to lifetime limitations and demand is high due to the fact that total demand for metals is growing. In other words, even with 100% EOL recycling, demand on the input side could not actually be met.

Hence, expanding consumption means virgin input is always necessary even with 100% EOL recycling. Therefore, allocating avoided burden by recycled content does not necessarily make sense as the demand for virgin input may be considered to be equally shared by all products, even those with high recycled content. Moreover, with increased recycled content one may be replacing recycled materials from other systems (in a consequential approach) without any additional environmental benefits.
This leads to a conclusion in Frees (2008) that the avoided burden should be allocated via EOL approach, not by recycled content.

In Frees (2008) a model is used that further links supply and demand price elasticity to the avoided burden: depending on the elasticity, recycled material replaces virgin or other secondary material in open-loop recycling. Although recent and detailed information on price elasticity was not available, Frees (2008) concludes that the supply elasticity for aluminium and steel scrap is close to zero. According to their model, this means that 100% virgin material is replaced.

2.3 Life span of product (differs for packaging and bridges)

An important factor in the decision which approach to use in an LCA may be the life span of the product under consideration. As Frischknecht (2010) points out, the EOL approach can be seen as a form of borrowing from the future. This is especially the case for long-lasting products such as buildings or bridges. One may argue that at the time of performing the LCA it should be reasonably certain that at the point in time when the product is discarded or dismantled, the embodied materials *will* actually be recycled (that is, there will be sufficient demand). As the product is longer lived, this is harder to prove.

The recycled content approach, on the other hand, accounts only for recycling that has already taken place. It therefore may be regarded as a ‘safe’ approach in the case of foot printing, where emphasis is on assessing *actual* effects. However, the recycled metal content does not stimulate to keep the metal in the loop and thus make it available for other uses which is contrary to the end-of-life recycling approach. A recycled content approach for long-lived products is also a reflection of past industry performance, in terms of how much metal was produced many years ago and subsequently recovered into a particular product, rather than reflecting the life cycle performance of a product designed and produced today and recovered in the future.

One could argue that in the case of metals, the future prospects for recycling are good, certainly on time scales of several decades. With emerging economies increasing the competition for ever scarcer materials, the demand for recycled materials will remain high.

Moreover, the argument of borrowing from the future is weak in the case of packaging, that has a short life span and cycles through the economy fairly quickly.

We can conclude that for packaging materials which have a short life span (maximum some years and in general some months) the EOL approach is appropriate.

2.4 Choice of approach and goal of the LCA

In principle, all methodological choices in LCA should be made to suit the goal as it is defined at the starting point of the analysis (ISO 14040). However, for the choice of approach to model recycling, the goal typically provides no guidance (e.g. Frischknecht, 2010). It involves a choice based on other criteria.

Frischknecht (2010) lists a number of criteria that can provide a basis for this choice. He relates the EOL approach to the 'weak' definition of sustainability and the recycled content approach to the 'strong' definition of sustainability. In the EOL approach, one may be "*borrowing environmental loans from future generations for man-made capital potentially being reused or recycled in the future*" (Frischknecht, 2010).

ISO 14040/44 does not provide specific guidance on the issue, apart from distinguishing explicitly the situation in which material undergoes changes in inherent properties (quality loss) and the situation in which it does not. In the latter, closed-loop recycling applies and no allocation is necessary (see Chapter 2). ISO 14044 seems to suggest that when end-of-life material of product A is input to product B without change in inherent quality, the allocation to product A would be the same as in case of closed-loop recycling. This is essentially the EOL approach.

Open-loop recycling applies if material is recycled into another system and the material undergoes a change to its inherent properties. In this case, the normal preferences for allocation apply. It is interesting to note that instead of allocating recycling and avoided primary production in some way, one can also allocate a fraction of the entire preceding life cycle (product A) to the secondary material as a useful co-product. As this approach is very uncommon it will not be discussed here. We refer to the ILCD Handbook for detailed discussion.

The PAS2050 guidelines for carbon footprint studies state:
"If the recycled material maintains the same inherent properties as the virgin material input, the emissions and removals arising per unit (E) from that material shall reflect the product specific recycling rate based on the calculation given in this clause (closed-loop approximation method)."
This closed-loop method means an end-of-life approach, so states Annex D3 (PAS2050, 2011).

ILCD Handbook (EC, 2010)
Important is that the allocation is done - strictly spoken - not between the first and second life cycle, but between the two co-functions that the reused, recycled or recovered good performs once for the primary product and ones (sic) for further products as the secondary good.

We conclude that for metal packaging both ISO 14.040/44, PAS2050 and the ILCD Handbook support an EOL approach.

2.5 Micro and macro assessments

Life cycle assessments can be performed at a variety of levels and with a variety of goals. In the ILCD Handbook (EC, 2010) macro-level versus micro-level assessments are distinguished. Micro-level studies typically involve individual products, focusing on e.g. optimising product design or foot printing. Macro-level studies involve larger-scale transitions in production or consumption that have structural consequences outside the decision context. Examples of this would be a comparison of use of biofuels instead of fossil fuels for transport or a life cycle based tax on packaging materials as was introduced in the Netherlands in 2008.

Apart from the distinction of micro and macro-level, the ILCD Handbook stresses the differences between the *attributional* and *consequential* implementations of LCA. Both may be used in micro-level as well as macro-level assessments, but the choice of approach may have consequences for other methodological choices such as allocation. Although the choice for attributional and/or consequential modelling has to be made for each specific context, in a rough description one could say that attributional modelling is dealing mostly with systems as they really are and aiming at past or current situations. Consequential modelling deals with potential situations (future) and changes that may occur in external systems.

Therefore, macro-level assessments may often be consequential but this is not necessary the case. The Dutch packaging tax is based on the current life cycle environmental impacts of packaging materials. This is a macro-level issue, but the approach is primarily attributional. An EOL approach was followed in the calculation of tax levels per material (CE, 2007), modelling the recycled content of metals via the closed-loop, attributional approach and the excess recycling rate for metal packaging in the Netherlands via EOL recycling/ avoided burden.

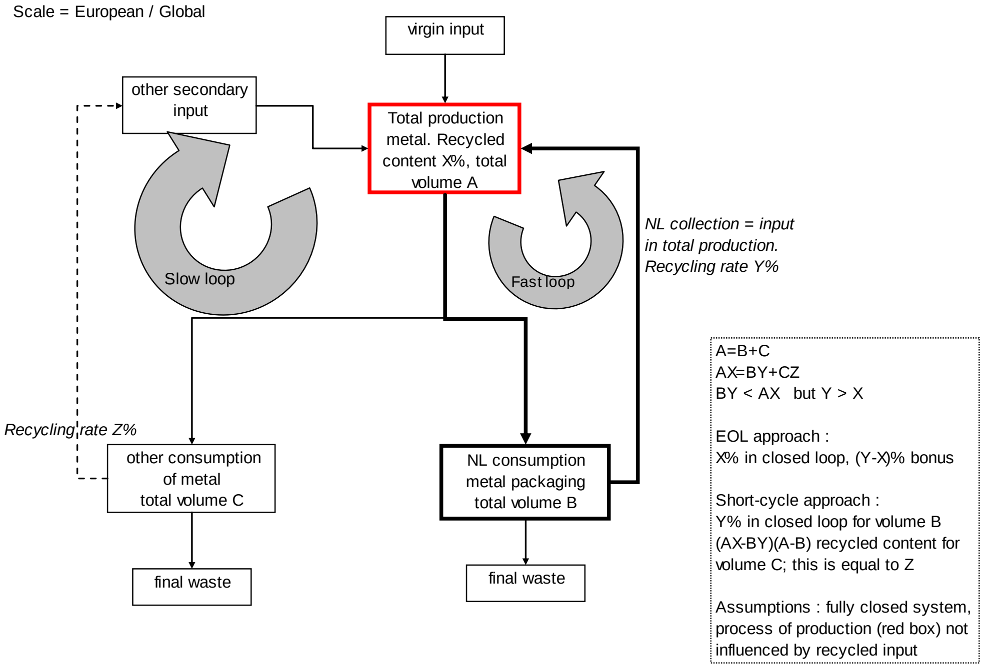
Is another approach feasible for this type of macro-level policy support?

Packaging materials are typically part of a much larger flow of those same materials that are used in several applications. There is no evidence to suggest that changes to external systems will occur even though metal packaging materials have a very short rotation time compared to other applications.

2.6 Packaging in the complete metal production

One could therefore take the view that the recycling rate for metal packaging can be modelled as being in closed loop (Figure 1).

Figure 1 Simple view of total production and consumption system with packaging in a fast loop and other products in a slower loop



This is in fact entirely equivalent to the EOL approach in terms of avoided virgin material production. A 'problem' is caused, however, by the fact that the inventory (energy, emissions, co-products) of the production process often depend on the recycled content in the input materials. A solution to this is described in detail in Annex A in order to avoid the double accounting of avoided virgin material production.

2.7 Conclusions

There are several (value-based) arguments to choose for the EOL approach to model recycling within LCAs in the case of metals, specifically in packaging application:
- there is no quality loss, so no effort required to apply secondary metals;
- the demand for secondary material is high and will be high in the foreseeable future;
- recyclability may be hampered by design and use of alloys, so design for recyclability should be stimulated; this is only an issue for metal contained within products, not for metal packaging;
- metal packaging has a short life span, thus it is certain that the secondary material provided will be used.

There are still circumstances that may require a different approach, such as consequential modelling for increased recycled content. In that case, good care should be taken to determine whether the extra recycled input 'replaces' virgin material or recycled material from other systems (Frees, 2008). The ultimate choice of approach should be dictated by the goal and scope of the LCA being performed.

3 Conclusions and implications

3.1 Conclusions

Two main approaches to model recycling in LCA have been discussed and analysed: recycled content (cut off) and end-of-life (avoided burden).
For the fraction of materials in a product or system that can be considered to be in closed loop, there is no difference between the two modelling approaches.

The question therefore is how to deal with additional recycling or additional secondary input. There is no scientific criterion to value one over the other, but several value-based criteria that may aid the choice. There are good reasons to prefer an EOL approach within LCAs to metal in many circumstances, from the perspective of promoting recycling and rewarding recycling efforts. The arguments of ‘strong sustainability’ favouring recycled content are less important for metals because of their longevity and high demand.

The following arguments can be used to prefer the EOL approach to model recycling in the case of metal packaging:
– there is no quality loss, so no effort required to apply secondary metals;
– the demand for secondary material is high and will be high in the foreseeable future;
– recyclability may be hampered by design and use of alloys, so design for recyclability should be stimulated;
– metal packaging has a short life span, so EOL recycling figures can easily be predicted and monitored.

There are of course circumstances that may require a different approach, such as consequential modelling of increased recycled content or LCA of extremely long-lived products. The ultimate choice of approach should be dictated by the goal and scope of the LCA being performed. Also, when following predefined protocols, an EOL approach may not be allowed. Product Category Rules are especially important in this, as they may also prescribe an allocation approach.

There may be some practical obstacles to the EOL approach. Especially, availability of process data for systems with a low recycling rate may be a problem, but this can be solved by careful accounting and by allocation of negative avoided burdens (i.e. extra burdens) In practice this is no issue because the metal packaging market has a relatively low share in comparison to other markets such as transport and building & construction.

For some macro-level assessments, such as the attributional modelling that underlies the Dutch packaging tax (see CE, 2007), the EOL approach may be interpreted as having the entire recycling rate in closed loop. In such closed-loop cases, avoided burdens do not have to be calculated by system expansion (substitution).

3.2 Implications for company foot printing

For foot printing, existing protocols may demand evaluation via the recycled content approach from a strong sustainability perspective. Foot printing is not typically a consequential way of thinking but tries to be an accurate reflection of actual product chain properties. At the same time, foot printing is used to indicate the level of 'environmental friendliness' of the product with respect to other similar products. For metal products, the end-of-life recycling may be a better indicator of environmental friendliness than recycled content, as it fairly represents overall product chain properties.

We conclude that in the case of modelling the recycling within LCAs of metal packaging, it is justified to take the recycling rate in place of the actual recycled content, in order to take into account the virtual closed loop nature of metal recycling flows.

In a life cycle study involving different packaging materials, e.g. a comparison between a PET bottle and an aluminium can, choices concerning goal and scope need to be the same for the two systems under comparison. According to the arguments outlined in this report, however, the EOL approach might be preferred for the can and the RC approach for the bottle.

A major difference between the two materials is that in the case of plastic, the avoided emissions can only be determined once the actual application of the recycled material is 'fixed'. In the case of metals, the avoided emissions are clear as soon as the material becomes available for recycling although there may be minor variations.

The ISO 14044:2006 (in Section 4.2.3.7) standard states that in comparisons between systems 'equivalent methodological considerations' should be used, e.g. concerning allocation rules and system boundary. Equivalent is not necessarily identical. LCA practice with respect to allocation is already an area where different choices are made in systems within one comparison, e.g. dry-matter allocation for beef as a co-product for milk and substitution for manure as a co-product of pork when comparing 100 grams of pork with 100 grams of cheese in an assessment of impacts associated with protein-rich foods.

Each choice should be made to fit the goal as defined for the LCA comparison, but differences in parameters should be made explicit in the LCA reporting. Another solution would be to do a sensitivity analysis of recycling, using 0-100 (RC), 100-0 (EOL) and maybe 50-50 allocation. This means in the case of plastics one has to establish what the second life cycle actually is.

3.3 Implications for policy makers

Policies, packaging taxes of CO_2 labels, which use recycling figures for packaging should use the EOL recycling figure to calculate the environmental performance of metal packaging. For example, the Dutch policy makers have already followed this policy for the packaging tax and also the wider packaging policies.

Literature

Atherton, 2007
John Atherton
Declaration by the Metals Industry on Recycling Principles
In : The International Journal of Life Cycle Assessment, vol.12, No. 1 (2007); p. 59-60

CE, 2007
M.N. (Maartje) Sevenster, L.M.L. (Lonneke) Wielders, G.C. (Geert) Bergsma, J.T.W. (Jan) Vroonhof
Milieukentallen van verpakkingen voor de verpakkingenbelasting in Nederland
Delft : CE Delft, 2007

EC, 2010
ILCD Handbook : General guide for Life Cycle Assessment - Detailed guidance
Brussels : European Commission, Joint Research Centre Institute for Environment and Sustainability (JRC), 2010

Frees, 2008
Niels Frees
Crediting aluminium recycling in LCA by demand or by disposal : case study
In : The International Journal of Life Cycle Assessment, vol. 13, No.3 (2008); p. 212-218

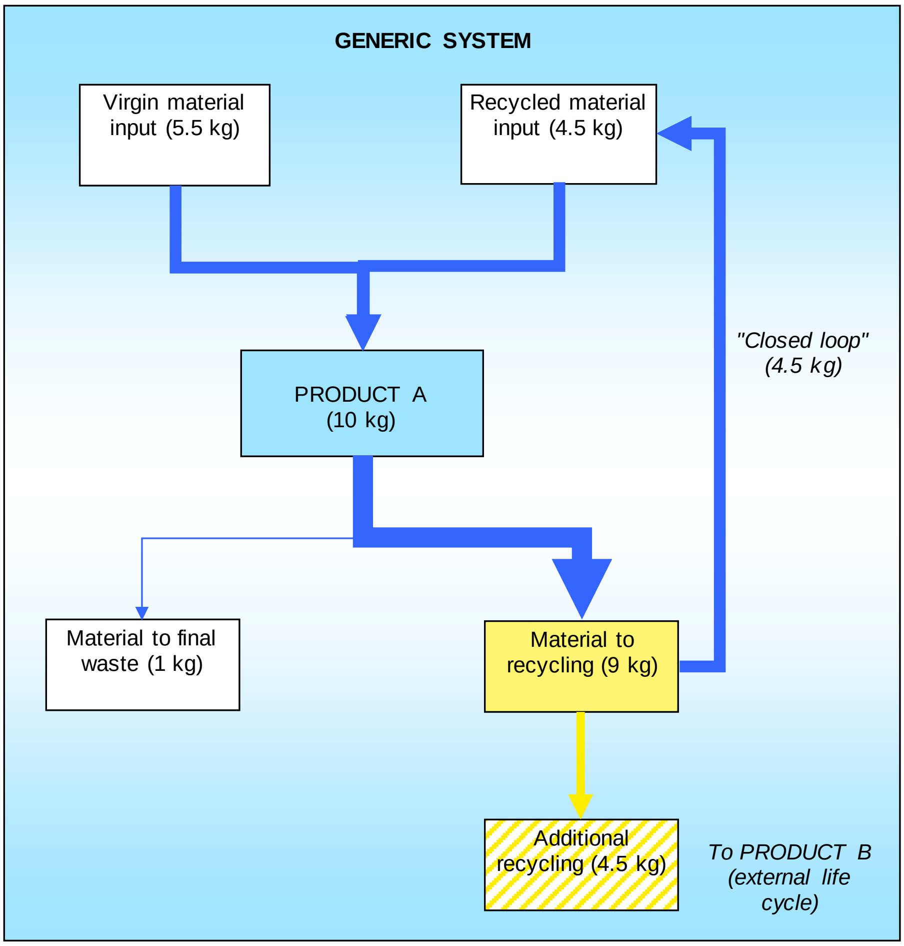
Frischknecht, 2010
Rolf Frischknecht
LCI modelling approaches applied on recycling of materials in view of environmental sustainability, risk perception and eco-efficiency
In : The International Journal of Life Cycle Assessment, vol.15, No. 7 (2010); p. 666-671

Annex A Recycling and LCA, differences EOL and recycled content

A.1 Recycled content versus end-of-life

To be able to discuss the differences between the two (extreme) approaches for allocation in the case of recycling, we define a generic product system first. This 'product' may be one drink can, or the entire packaging consumption of a country or a ton of average steel. The product is made of 55% virgin and 45% recycled (mono) material and 90% of the product is recycled after use. In Figure 2, the material flows are shown.

Figure 2 Material flows in generic system A



The closed-loop recycling does not have to be taken literal, but is typically used to indicate that part of the flow of secondary material overlaps for input and output, as long as the quality of the recycled material does not diminish. The environmental benefit of the 4.5 kg recycled material used in product B is more or less the same as the 4.5 kg recycled material used in product A. Therefore all recycled material can be considered to be in the same closed 'material' loop, even if they go into different specific products.

The issue in LCA is how to allocate the environmental benefits of recycling, with respect to the use of virgin materials, between product A and product B. Both are involved in the flow of secondary materials. There are two 'extreme' approaches for this, but there are also options to go in between.

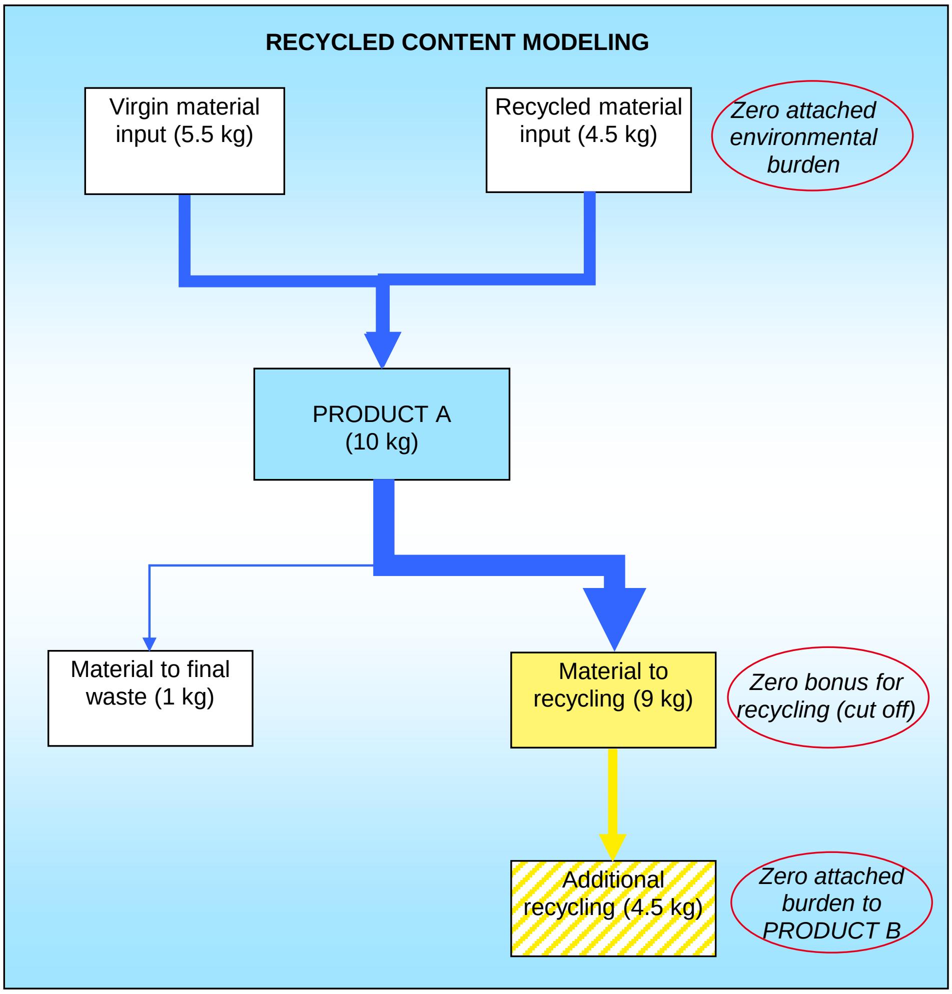
Below, we describe those approaches in terms of methodology without attaching any value choices to them yet.

A.1.1 Recycled content

The recycled content method takes the following approach:
- secondary materials that are input to a process have zero attached environmental burden except for energy use and transport for collection, sorting, et cetera;
- secondary materials on the output leave the product system without any further environmental burden (positive or negative); this is called *cut off;*
- the benefit of additional recycling goes entirely to product B.

This is shown in Figure 3.

Figure 3 Recycled content approach to generic system A



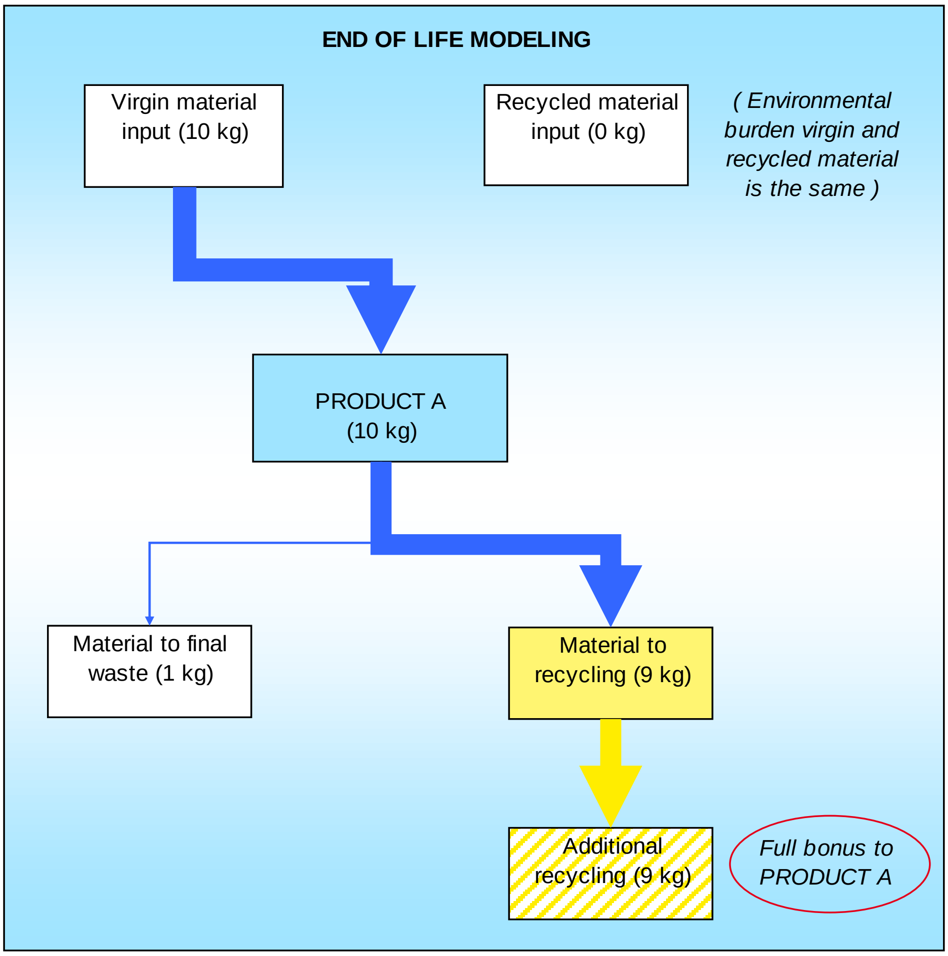
A.1.2 End-of-life

The end-of-life (EOL) method takes the following approach:

- secondary materials that are input to a process have the same attached environmental burden as virgin materials;
- secondary materials on the output side leave the product system causing extra environmental burden (energy use for melting and transport for collection, sorting) as well as an environmental bonus (*avoided burden* virgin material production);
- the benefit of recycling goes entirely to product A.

This is shown in Figure 4.

Figure 4 End-of-life (EOL) approach to generic system A



A.1.3 Net Scrap approach

A more transparent approach similar to that described Figure 2 (generic system) and also described in EN 15804. The overall effect is to give the same result as the end-of-life approach but models materials flows as they are in reality. Recycled material used in product A (4.5 kg) is considered burden free. The net flow of recycled material leaving the system (9-4.5=4.5 kg) is attributed to product A according to the burdens and avoided burden as described in the end-of-life approach. This means that the production process using the recycled material shows lower burdens (reflecting reality), but any additional material recycled is also credited to the product to reflect the good end-of-life performance of product A.

A.1.4 ‘50-50’ approach

A combined approach would be to divide the ‘bonus’ over product A and product B. The so-called ‘50-50’ approach prescribed by the German environment Agency UBA in assessments of packaging is an example of this. It should be noted that in a 50-50 approach, not only the ‘bonus’ has to be divided over product A and product B, but also the recycling process (collection, sorting) and the avoided final waste treatment. Of course, the distribution of benefits/burdens between product A and B could also be 80-20 or 30-70, but this is less common.

A.1.5 Co-product approach

The EOL and 50-50 method for attributing benefits of recycling discussed above is a form of system expansion (substitution) but the recycled content approach is essentially a form of allocation. In this cut-off approach, the allocation of the previous life cycle to the material going to recycling is 0%. One could also choose e.g. economic allocation, regarding the recycled material as a useful co-product of the product itself and attributing some environmental burden to it by economic value. This is a very uncommon approach, however, and cannot be easily implemented because the economic profits do not arise at the same point in the life cycle nor go to the same party. We will not discuss this any further.

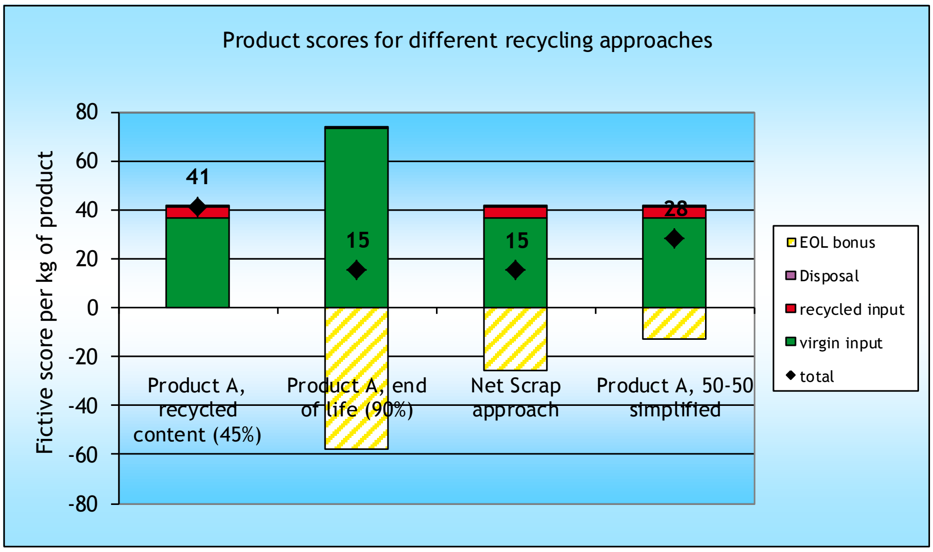
A.2 Examples

To demonstrate the difference in results of LCA between a recycled content and an EOL approach, we model a product according to the approaches shown in Figure 5 and Figure 6. Also, a net scrap and a 50-50 approach is modelled, using the generic system shown in Figure 2 with 4.5 kg of recycled material in closed loop and a 50% bonus for 4.5 kg extra recycling (so effective bonus for 2.25 kg).

The ‘bonus’ consists of the difference between virgin and recycled input material. Hence, 50% recycled input in the recycled content approach gives exactly the same numeric result as 50% recycling after use in the EOL approach.

The chosen example is valid for all materials, but of course for some materials the difference between virgin and recycled input material may be smaller or larger. Figure 6 shows the different scores.

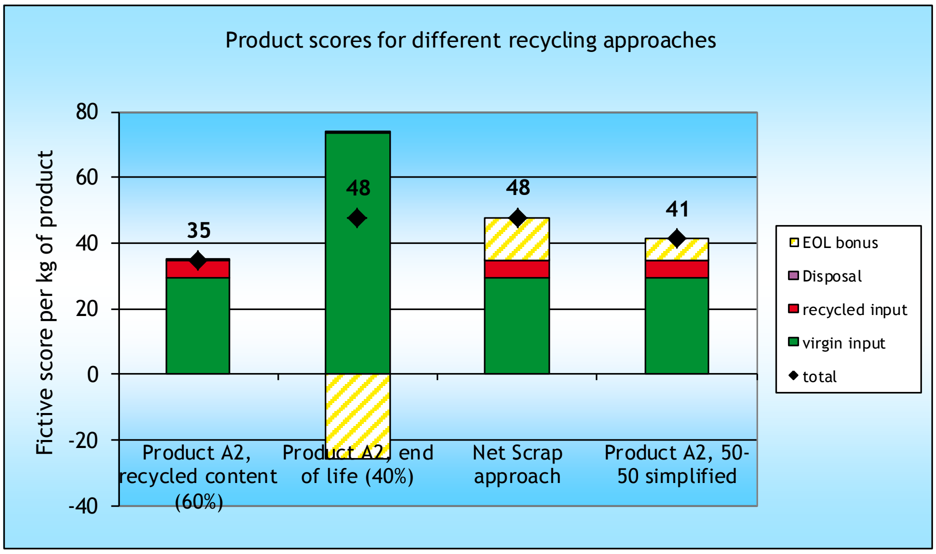
Figure 5 **Example of scores for the recycling approaches described in Section A.1 (EOL recycling rate higher than content). The black dot indicates the net score; the net score is also shown as value**



Clearly, the choice of approach influences the result of the assessment considerably. In this case, the EOL recycling rate is higher than the recycled content. Therefore, the EOL approach gives the lowest (i.e. best) score. The 50-50 approach results in a score that is the average of the two approaches.

If the EOL recycling rate is lower than recycled content (Figure 6) the EOL approach gives the highest score.

Figure 6 **Example of scores for the recycling approaches (recycling rate lower than content)**

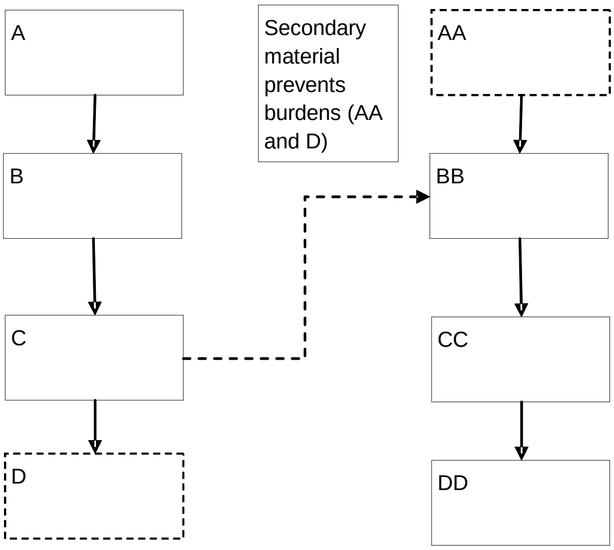


The only situation that is insensitive to the approach chosen is when recycled content and EOL recycling are the same. This is a full closed-loop situation, and thus it does not matter which allocation model is applied.

A.3 Actual avoided burden

In all cases, when recycling is part of a system being analysed, it should be established in the first place what the actual avoided burden is. Generally speaking, this will be the combined effect of avoided virgin material production and of changes in processing energy due to input of secondary materials. To establish the first avoided burden, the practitioner determines exactly where the recycled material enters the new life cycle (Figure 7). Preceding steps in the second life cycle are thus avoided, as well as the original waste treatment in the first life cycle.

Figure 7 Avoided burdens of material input



It is not necessarily the case that AA = A and BB = B, et cetera. For example, secondary glass can be input into process BB replacing sand, soda, et cetera, and delivering exactly the same quality output glass. As the secondary glass is easier to melt than the virgin materials, however, the energy required in process BB is lower than in process B. The difference is thus the second part of the total avoided burden as stated above. For steel, the energy use is also variable with recycled input (content) and for several other metals the same may be the case, also as a result of larger impurities in the virgin material.

The processing energy should in principle always be determined for the recycled input percentage of the real system(s). When determining the avoided burden of additional end-of-life recycling, this is not possible. If process BB can be subdivided into processing of primary and processing of secondary materials, as is the case for glass, the avoided energy use can easily be modelled.

For converter steel production, the situation is more complex. Scrap steel is often used for cooling at a specific stage in the process and thus in theory 'requires' no energy at all. As the whole process is designed to function like this, zero energy for the recycled material in process BB is not realistic, however. A solution is to take into account only the avoided virgin material production (pig iron) and assume that all energy in process BB is equally distributed over the inputs and in fact equal to B.

Another solution is to use electro steel production with 100% scrap inputs as the second system. In that case the avoided burden is : BB minus (A+B).
AA does not exist in this case (Figure 7). In practice, these approaches yield fairly similar results, at least for climate change impact (see CE, 2007).