Evaluating Open-Loop Recycling Allocation Methods in Life-Cycle Assessment

White Paper

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for

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Life-Cycle Assessment

Companies, academics, and government agencies use the Life-Cycle Assessment (LCA) framework to evaluate the environmental impacts of product systems. A life-cycle sequence considers all of the phases a product goes through from "cradle-to-grave," as illustrated in Figure 1. The LCA methodology enables calculation of environmental impacts from raw material inception, production, use and disposal at a product's end-of-life as well as transport between these phases.

This paper outlines ClearCarbon's approach to using LCA allocation methods when evaluating the environmental impacts of recycled materials. For further discussion and application of the concepts presented in this white paper, please refer to the case study *Allocation of Greenhouse Gas Emissions in Open-Loop Recycling: Case Study*.

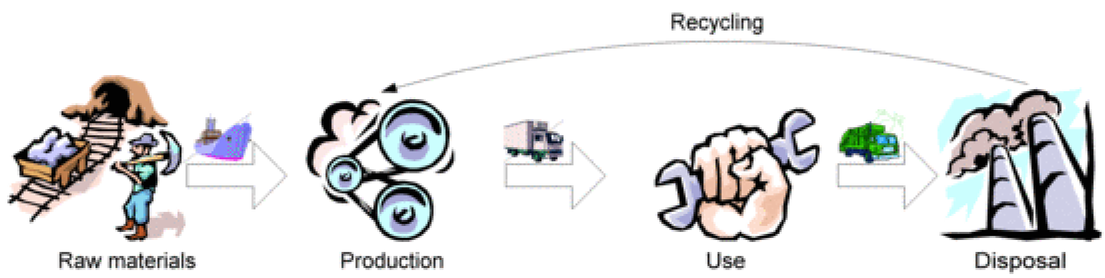

Figure 1: Product Life-cycle Phases from Cradle to Grave[1]

The Problem: Allocating Environmental Impact for Open-loop Recycling Processes

Open-loop recycling involves the conversion of material from unknown upstream products into unknown downstream products. Allocating environmental impacts in an open-loop recycling system presents a challenge when conducting an LCA. The ISO 14041 standards which govern the LCA methodology do not explicitly address how to allocate emissions to a single product in an open-loop recycling system. In contrast, a product subject to closed-loop recycling presents less methodological issues, as a product stays within the same product system and impacts are more easily assigned (i.e., a plastic bottle is recycled again into a plastic bottle).

In open-loop recycling, processes that provide waste treatment for products upstream of the recycling facility also provide recycled material for products downstream of recycling. In addition, changes in the amount of recycled material delivered by, or used in, the life-cycle of a product will affect the environmental burdens of other product life-cycles. Consequently, the way in which environmental impacts are distributed among materials in open-loop recycling systems has been widely criticized. There are many uncertainties about allocating environmental impacts at a product's end-of-life when a material can be potentially recycled several times.

[1] Taken from LCA Center, Denmark. *LCA in general*. 2010 Available from: http://www.lca-center.dk/cms/site.aspx?p=358

Figure 2 shows a simplified diagram of the process and material flows in an open-loop product life-cycle sequence. Product 1 (P1) is produced from the virgin raw materials extracted in the first step (V), also called the raw material inception phase. At the end of P1's useful life, it is recycled into material used to make product 2 (P2). Again, at the end of P2's useful life, it is recycled into material used to produce product 3 (P3). At the end of P3's useful life, it is disposed of in some manner such as landfilling or incineration and leaves the sequence of product recycling.

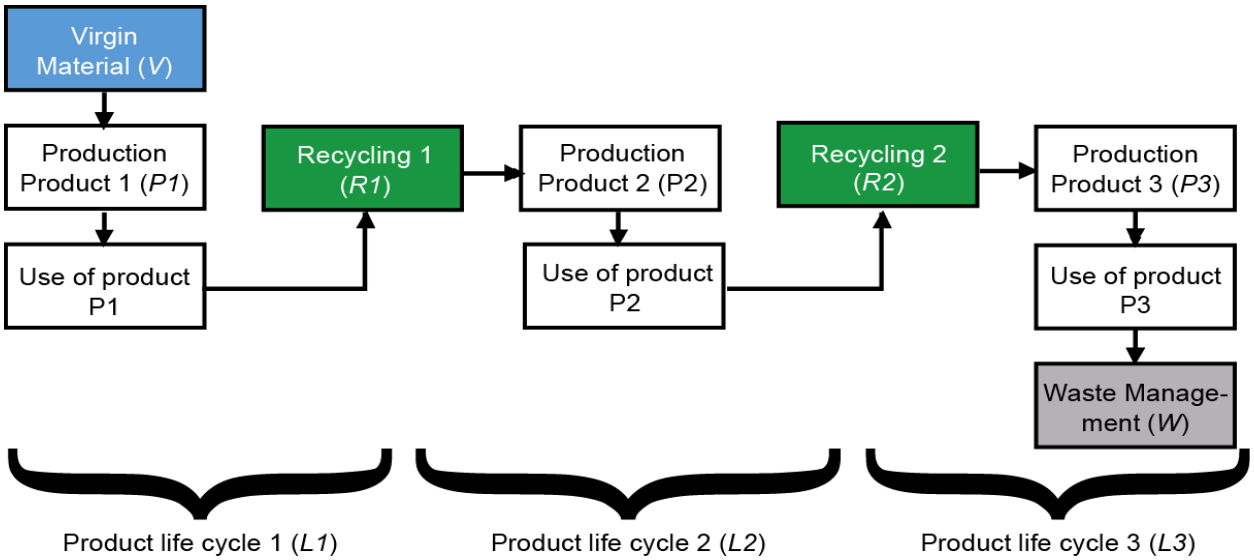

Figure 2: System Boundaries for Product Material Flows and Open-loop Recycling[2]

Assuming P2 is the known product, the problem illustrated by Figure 2 is the lack of knowledge around what P1 was before being transformed into P2, and similarly, what P3 will be after P2 is recycled. Without this specific product knowledge, **how, then, should the environmental impact, or "burden," associated with recycling, virgin material inception and final disposal be apportioned among the products in open-loop recycling?**

The Solution: Transparent Use of Allocation Methods

In practice, LCA uses several different methods to attribute the environmental impacts associated with virgin material inception, recycling, waste treatment and the provision of newly recycled material. These allocation methods rely on conceptually based assumptions that can be used to determine environmental impacts for recycled materials, including common plastics and metals used in packaging. However, a negative consequence of the flexible recycling allocation rules is that different results may be obtained from otherwise equivalent studies.

In order to address this problem, ClearCarbon recommends that products undergo critical review and receive independent examinations of the applied allocation method, and that producers create a report with transparent communication of the study and its results. Transparency in the results allows other

[2] Ekvall, T. and A.-M. Tillman, *Open-Loop Recycling: Criteria for Allocation Procedures.* International Journal of Life Cycle Assessment, 1997. 2(3): p. 155-162.

companies, academics or government agencies to understand the assumptions made in the analysis and then compare products with similar boundaries. If there is no definitive answer on how to allocate the burdens associated with virgin material inception, recycling and final disposal in an open-loop product recycling scenario, **ClearCarbon recommends defaulting to a 50/50% material inception and 50/50% end-of-life allocation method**.

METHODS IN RECYCLING ALLOCATION

LCA literature proposes various methods to deal with the uncertainty of assigning environmental impacts. Generally these methods address life-cycle impacts in terms of an overall product system; however, Figure 3 considers these impacts at two discrete phases in the life-cycle: raw material inception and end-of-life.

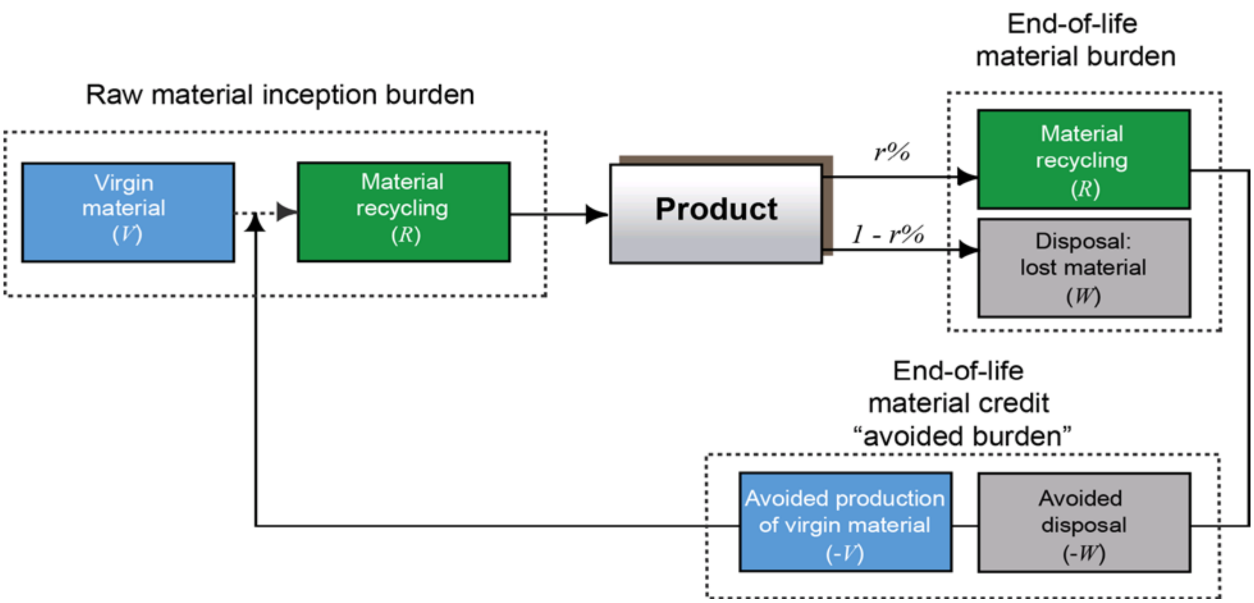

Figure 3: Open-loop Recycling – showing raw material inception burden as a blend of virgin and recycled material, end-of-life material burden as recycling and disposal and end-of-life credit as avoided virgin production and disposal

Three Methods for Calculating Raw Material Inception Impact

To deal with uncertainties, three methods for allocating material inception impact for recycled inputs are considered in this paper: 100% recycled material burden, 100% virgin material burden, and 50/50% material burden. Each method offers a different incentive surrounding recycling, and it is important that each is paired with its congruent allocation method at end-of-life.

100% recycled material burden: *This method provides no incentive for developing recyclable products, only for using recycled materials.* In this method, the process impacts required to create recycled material (*R*) from post-consumer scrap are taken into account: e.g., collection, transport, sorting, grinding, washing, melting. Use of this method implies that the recycled material should only be assigned environmental impacts directly caused by the new product, regardless of what the product was before it was recycled.

Burden of recycled material input (M_R):

$$M_R = 100\% \cdot R$$

100% virgin material burden: *This method provides no incentive for using recycled materials, only for developing recyclable products.* This method attributes 100% of the virgin material production burden (V) to the recycled material. Use of this method implies that recycled materials should be assigned burdens that would have occurred during its theoretical production from virgin materials. It follows that credit will be given for avoided virgin material production at the product's end-of-life.

Burden of recycled material input (M_V):

$$M_V = 100\% \cdot V$$

50/50% material burden: *This method of allocation promotes an underlying rationale that both supply and demand for recycled material are necessary to enable recycling.* In general, this method is a more conservative approach to emissions accounting for recycling. The 50/50 method attributes the impacts of producing a recycled material as a percentage of virgin production (V) and as a percentage of recycled material production (R) (e.g., collection, transportation, sorting, grinding, melting). This method follows the reasoning that a portion of the impact results from upstream virgin material inception and from the recycling of materials. The burden is therefore an average impact, apportioned equally among materials.

Burden of recycled material input ($M_{V/R}$):

$$M_{V/R} = 50\% \cdot V + 50\% \cdot R$$

Three Methods for Calculating End-of-Life Impacts

Cradle-to-grave LCAs include impacts from raw material inception as well as impacts from product disposal / end-of-life. In this analysis, three end-of-life allocation methods are considered. Each method uses published material recycling rates (r) to appropriately assign environmental impacts.

Waste treatment only end-of-life: *This method provides little incentive for developing recyclable products, only for using recycled materials.* This method considers the impacts from the waste stream percentage ($1 - r$) that is landfilled (W_L) or incinerated (W_I) as a burden and attributes a credit to the waste stream that is averted to recycling (r). This method assumes the burdens from recycling are assigned to the next downstream product system. In practice, this method should be used when 100% of the raw material inception burden is placed on recycled materials, as it assumes that the credits associated with using recycled material, i.e. credits for avoided virgin material production, lie outside of the product system boundary.

Material burden and credit at end-of-life:

$$EOL_W = [W \cdot (1 - r\%)] - [W \cdot r\%]$$

where

$$W = W_I \cdot 20\% + W_L \cdot 80\%$$

100% end-of-life credit/burden: *This method provides no incentive for using recycled materials, only for developing recyclable products.* The material percentage that enters the recycling stream (*r*) is apportioned a burden of 100% due to recycling processes and a 100% credit from avoided virgin material production. In practice, this method should be used only when 100% of the raw material burden is placed on virgin materials (as opposed to 50/50%). Again, the environmental impacts associated with waste are accounted for in the waste stream percentage that is landfilled (W_L) or incinerated (W_I) and a credit is given for the percentage that is diverted to recycling, thereby avoiding landfilling or incineration.

50/50% end-of-life credit/burden: *This method of allocation promotes an underlying rationale that both supply and demand for recycled material are necessary to enable recycling.* The material percentage that enters the recycling steam (*r*) is apportioned a 50% burden due to recycling processes and a 50% credit from avoided virgin material production. The environmental impacts associated with waste are accounted for in the percentage of a material waste stream that is landfilled (W_L) or incinerated (W_I), i.e. the burden, and a "credit" for the percentage that is diverted to recycling, thereby avoiding landfilling or incineration. In practice, this method should be used only when the raw material burden is 50% on virgin materials and 50% on recycled materials.

Material burden at end-of-life:

$$EOL_{100\%B} = [100\% \cdot R \cdot r\%] + [W \cdot (1 - r\%)]$$

Material credit at end-of-life:

$$EOL_{100\%C} = [100\% \cdot V \cdot r\%] + [W \cdot r\%]$$

where

$$W = W_I \cdot 20\% + W_L \cdot 80\%$$

Total end-of-life impacts:

$$EOL_{100\%} = EOL_{100\%B} - EOL_{100\%C}$$

Depending on the allocation methods chosen, the overall product life-cycle impact from material inception and end-of-life phases are then calculated using the following formulas:

Life-cycle emissions (raw material inception and end-of-life):

$$Impact = M_R + EOL_W$$

$$Impact = M_V + EOL_{100\%}$$

$$Impact = M_{V/R} + EOL_{50/50\%}$$

Conclusion

There is no definitive guidance on how to allocate the burdens and credits associated with recycling, virgin material inception, and final disposal in open-loop recycling. ClearCarbon defaults to 50/50% for raw material inception and 50/50% at end-of-life when conducting LCAs due to calculation simplicity, logic, and feasibility when little is known regarding the upstream or downstream products. It is important for the LCA community to move towards a consistent choice of methodology when considering product system boundaries, as this is the only way to enable comparison across product systems. Transparent descriptions around the choice of end-of-life methodology are the only way to assure consistency between analyses. The recycling allocation case study published by ClearCarbon demonstrates the significant effect that decisions about end-of-life allocation methods can have on the overall life-cycle assessment result.

GLOSSARY

Material Inception	Procurement of material for use in manufacturing a product. Can be virgin or recycled material. Another term for virgin material inception is virgin material extraction, or removing materials from the earth.
Burden	The energy and emission impacts associated with the inception of a material (e.g. extraction, refining, processing), its recycling (e.g. collection, transportation, sorting, regrinding, melting, etc.) or its ultimate disposal at end-of-life.
Credit	The avoided energy and emissions impacts when recycling processes are utilized, resulting from avoided virgin material production and avoided waste treatment.
Downstream Products	Materials or products created after the current product is recycled.
Upstream Products	Materials or products existing before the current product.
Closed-loop Recycling	Recycling materials from a known product system back into the same product system (e.g., recycling a PET bottle into a PET bottle). Generally completed at facilities with full asset control or in recycling systems designed for specific products.
Open-loop Recycling	A recycling system in which there is no specific knowledge of the upstream products used to create recycled material and of downstream products that will be created from the recycled material. Curbside recycling is an open-loop recycling system.