LCA Case Studies and Discussions

Economic Allocation in LCA: A Case Study About Aluminium Window Frames

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DOI: http://dx.doi.org/10.1065/lca199912.008

Abstract. A traditional problem in LCA is how to deal with processes where recycled material is used as an input or where the output of a process is further used as raw material in another product system (open-loop recycling). Allocation is needed to partition the responsibility for the environmental impacts caused by the raw material extraction, the recycling and the final disposal of a material over different product systems in some proportional shares. The norm ISO/DIS 14'041: 1998 now explicitly allows the use of an economic value as a basis for the allocation of open-loop product systems, where material is recycled into other product systems while undergoing a change in its inherent properties.
In a case study for aluminium window frames, an economic allocation procedure for aluminium is developed based on different market prices for secondary materials with different alloy content. Market prices are assumed to reflect the functionality of a material quality within a techno-economic system. Therefore, market prices permit the qualitative description of the degradation of a material over a product system. Based on this qualitative degradation, a 'relative resource consumption' can be defined. This relative resource consumption is used to allocate the environmental impacts related to recycled material entering or leaving the product system under study.
The results of the new allocation principle are compared to results of a former study on window frames out of various materials, elaborated by EMPA in 1996. The conclusions underline the importance of the recycling of aluminium with a high quality and give some criteria for a more ecological design of aluminium windows. Finally, methodological advantages and obstacles of the presented economic allocation procedure are pointed out.

Keywords: Allocation; aluminium; case studies; economic allocation; functionality; LCA; material quality; open-loop recycling; window frames

1 Introduction

A current problem in LCA is how to deal with material and energy flows which affect other processes or product life cycles not included in the analysed system. If not avoidable, allocation is needed to partition the responsibility of the environmental impacts in some proportional shares. Allocation is especially required in open-loop recycling:

- When recycled material or energy from the life cycle studied is used outside the analysed system,
- when recycled material or energy produced outside the analysed system is used in the life cycle studied,
- when recycled material or energy from the life cycle studied is used outside the analysed system as an input to the following systems of a cascade.

In product systems where recyclable material is involved, possibly all of these three examples will be found for the same material.

During the last years, several allocation rules for multi-input/output-processes as well as for cascade systems have been proposed (Nordic, 1995). For recycling processes, these rules are only applicable to a certain extent since in-product systems including recycled materials and recycling processes are combined in both allocation situations (→ *Fig. 1*).

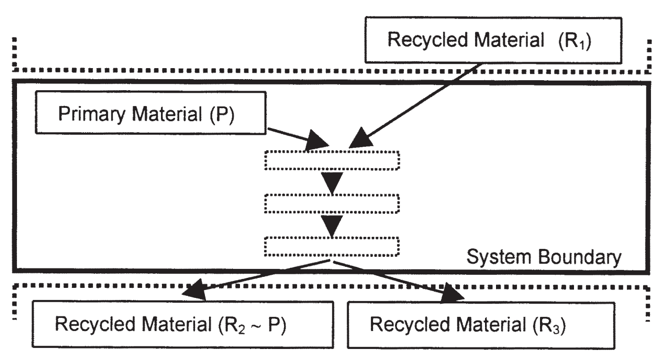

Fig. 1: Product systems with recyclable materials: A combination of multi-input/output processes in cascade use including changes of the inherent properties of the material over the life cycle

The norm ISO/DIN 14'041:1998 describes a three step procedure on how to deal with situations where an allocation is necessary. As a first step, wherever possible, allocation should be avoided. Especially for the ecological evaluation of products and for the application of LCAs in product design, the expansion of the system is often not desirable. It implies a greater effort for data collection, evaluation and interpretation without focusing on the scope of the study.

As a second step, the inputs and outputs of a system should be partitioned in such a way that reflects the underlying physical relationship between them. First of all, it can be argued that material flows are mainly determined by the underlying economic system and not by physical relationships (HUPPES, 1992; FRISCHKNECHT, 1998). Secondly, in the case of open-loop recycling, the change in the physical or chemical properties of a material cannot be described consistently using only one parameter to make its choice arbitrary.

With the approval of ISO/DIN 14'041:1998, as third step, a new possibility for allocation has become accepted: The norm now explicitly allows the use of the economic value as a basis for the allocation of the open-loop product systems:

"Where physical relationship alone cannot be established or used as the basis for allocation, the inputs should be allocated between the products and functions in a manner which reflects other relationships between them. For example, environmental input and output data might be allocated between co-products in proportion to the economic value of the products" (ISO/DIN 14'041:1998, chap. 6.4.2, para. 3),

and under the point on 'Allocation procedures for recycling' (ISO/DIN 14'041:1998, chap. 6.4.3, par. 2):

"*An open loop allocation procedure applies to open-loop product systems where the material is recycled into other product systems and the material undergoes a change to its inherent properties. The allocation procedures for the shared unit processes mentioned above should use:*

- *physical properties*
- *economic value (e.g. scrap value in relation to primary value), or*
- *the number of subsequent uses of the recycled material (e.g. rubber used in a tire to rubber in the shoe sole to energy recovery from rubber incineration)*

as the basis for allocation".

In the following, an economic allocation procedure is developed for the aluminium of window frames which is based on different prices for secondary qualities of aluminium scrap with different alloy content. The results of the new allocation principle are compared to results of a former study on window frames out of various materials (RICHTER, 1996a).

2 Allocation in the Former EMPA-Window Study

In (RICHTER, 1996a), the environmental burdens of the primary and secondary materials, as well as the outputs, were allocated according to the following principles:

- Primary material as input: The environmental burden of the raw material extraction and processing is included entirely in the system studied
- Recycled material as input: The environmental effects of collecting, processing and reintegrating the material are included in the system
- Recyclable materials such as output: Any environmental effects of collecting and recycling are excluded (as a burden for the next product system)
- Non-recyclable wastes: The effects of disposing non-recyclable wastes are included in the system

In **Fig. 2**, these principles are illustrated:

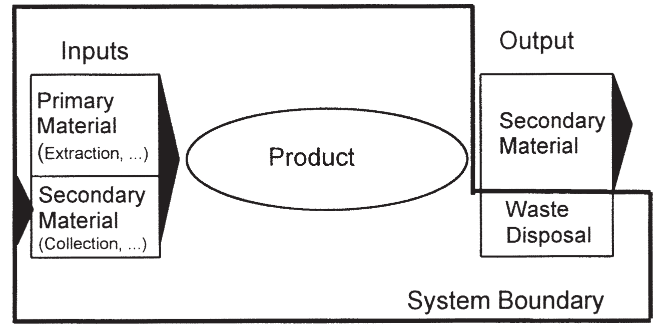

Fig. 2: System boundaries and material flows

This 'conservative' allocation procedure allows one to estimate the relative importance of a chosen allocation and is therefore proposed as a first step in cases where allocation is unavoidable (Nordic, 1995).

The easy-to-use-advantage of this procedure implies some disadvantages:

- The use of secondary material is favoured due to the fact that no environmental burden of the primary material production for the secondary material is implied and due to the frequent lack of complete data on the recycling processes.
- No emphasis is given to the quality of the secondary material at the end of the life cycle.

3 Economic Allocation Procedure

The economic allocation procedure corresponds to ISO/DIN 14'041 and is based on the following key assumptions:

From primary use to final disposal, materials run through a cascade of various product systems. Within each product system, the inherent properties of the material – the "quality" – is changed (SIRKIN et al., 1994). Based on the change in material quality, a relative "resource consumption" can be defined for a product system. Using this relative "resource consumption" as a criterion, the environmental effects of recycled material (its extraction as a primary material, its final disposal, the recycling steps) can be allocated to the product system under study.

The market price is considered an expression of the functionality of a certain material quality within a techno-economic system. Relative market prices are therefore a useful parameter to describe the "qualitative" gradation of a material.

It has to be stressed that this price-functionality-quality-relation is only assumed *for different grades of secondary material*. Scrap prices explicitly do not enter into the allocation procedure (in contrast to the example given in chapter 6.4.3, para. 2 of the norm ISO 14'041:1998). All in all, the aluminium scrap flows in Central Europe have to be considered very dynamic depending much on regional and technological developments. Therefore – in spite of depending indirectly on the price of primary material and on the functionality of the future secondary material – the scrap prices may strongly be influenced by other price relevant factors such as homogenity or dirtiness.

Mathematically, the environmental burdens of the inputs (primary and secondary material) are weighted according to their price in relation to the primary material (relative price = 1), the relative prices of the *recycled* output are used as the weighting factor to give credit in accordance to the remaining usable quality of the output material. For the system shown in **Fig. 1**, the "total"environmental burden is calculated as follows:

+		P*	[Primary material production]	**Input**
+	x*	R_1*	[Primary material production]	
+		R_2*	[Recycling process]	**Recycling**
+		R_3*	[Recycling process]	
-	y*	R_2*	[Primary material production]	**Credit for the quality of the recycled material**
-	z*	R_3*	[Primary material production]	
+		P*	[Final disposal]	**Relative contribution to final disposal**
+	x*	R_1*	[Final disposal]	
-	y*	R_2*	[Final disposal]	
-	z*	R_3*	[Final disposal]	
TOTAL			[**Material and energy flows**]	

with:

P: Quantity of primary material
R_1: Quantity of secondary material as input
R_2: Quantity of secondary material as output with equal inherent properties as primary material
R_3: Quantity of secondary material as output with changed inherent properties
X: Relative price of R_1 compared to P (relative price = 1)
Y: Relative price of R_2 compared to P
Z: Relative price of R_3 compared to P

A precondition for this allocation procedure is a stable price relation of primary and secondary material: the ratio of the LME-index for primary and secondary aluminium can be considered constant over the last years (1995 – 1998).

4 Comparison of Allocation Procedures: A Case Study on Aluminium Window Frames

To study the two allocation procedures, LCAs have been calculated for three alternative scenarios of an aluminium window including a Low-E glazing[1] (Richter, 1996b), altering the relation of primary and secondary material, as well as the allocation procedures (→ *Table 1*). The functional unit and the calculations for the scenarios 'SZFF 65/35 old' and 'SZFF 15/85 old' have been taken from (Richter, 1996a). To improve the inventory data for the aluminium recycling step for the window 'SZFF 100/0 new', data has been collected in German recycling plants.

The window 'SZFF 65/35 old' reflects the actual situation concerning the material composition of aluminium window frames in Switzerland, whereas a (future) closed loop-recycling situation is assumed in 'SZFF 15/85 old'. The material composition in scenario 'SZFF 100/0 new' is a hypothetical one to easily study the influence of the economic allocation procedure (→ *Table 1*).

For the calculation, a service life of 30 years is assumed. Heat losses through the window frame and the glazing are compensated by a LowNO_x- gas heating.

The inventory data of the three scenarios is assessed by the Effect-Oriented Classification (CML, 1992). Additionally, some waste parameters are calculated based upon Swiss legislation. The following graphs give some representative examples of the results. For graphic reasons, the material credit is subtracted from the frame material (→ *Fig. 3* to *Fig. 6, p. 82*).

The final disposal step of aluminium has not been included into the calculation, because corresponding technology has not been developed on a industrial scale in view of a growing global aluminium pool of 3.6% per year.

The credit given in the economic allocation procedure based on the remaining quality of the secondary aluminium (output) equals 80% of the frame and fittings material input. The remaining 20% represent the change of the inherent properties ('the loss of material quality') of aluminium and the aluminium losses during the recycling processes.

Table 1: Scenarios calculated for the aluminium window 'SZFF'

	SZFF 65/35 old	SZFF 100/0 new	SZFF 15/85 old
Composition input	65% primary material 35% secondary material	100% primary material	15% primary material 85% secondary material
Allocation procedure	Traditional allocation	Economic allocation	Traditional allocation
Recycling processes	BUWAL 133	– own data/EAA – detailed modelling	BUWAL 133

[1] Specifications: measures 1650 x 1300 mm, k_F = 1.9 W/m²K, k_G = 1.6 W/m²K

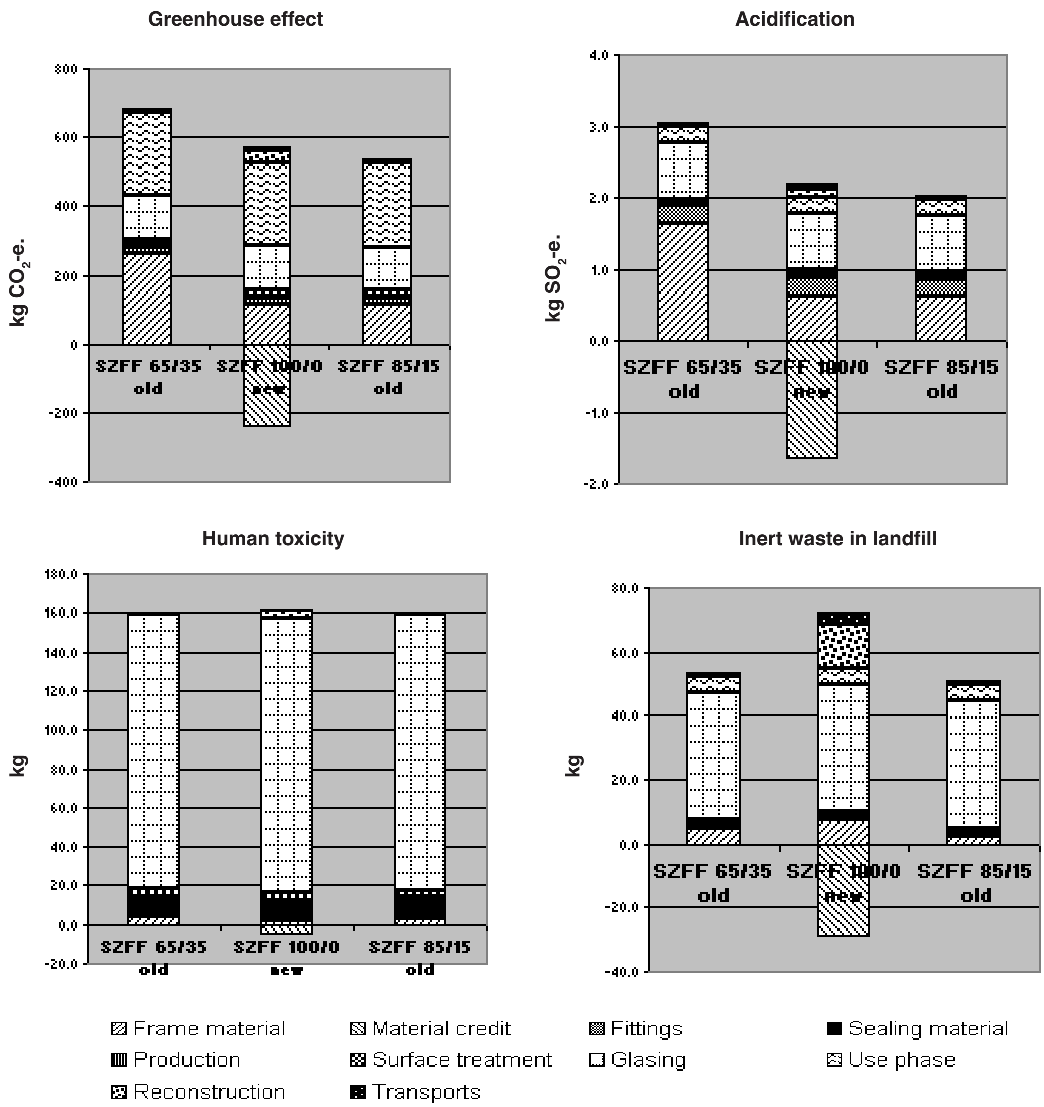

Fig. 3 to 6: A selection of representative effect categories and waste parameters

Compared to the scenario 'SZFF 65/35 old', the scenario with the economic allocation 'SZFF 100/0 new' shows an up to 30% better ecological profile in all the energy-related effect categories like 'Greenhouse Effect', 'Acidification, 'Ozone Depletion', etc. Due to the great influence of the Low-E glazing on all effect categories dealing with toxicity (e.g. 'Human Toxicity'), the effect of the allocation procedure for aluminium is not significant.

The environmental effects of 'SZFF 100/0 new' are in the same range as the 'future scenario' 'SZFF 15/85 old' in (RICHTER, 1996a).

As a consequence of the better data for recycling processes, the amount of the different wastes discussed is generally higher for the economic allocation scenario (e.g. 'Inert Waste into Landfill').

The material flows for recyclable aluminium have resulted in being very variable, depending much on the site-specific situation of the companies involved. Nonetheless, aluminium per se keeps its inherent properties during the recycling processes not depending on the further use of it. Asking for an explicit closed-loop recycling for aluminium windows (as assumed in 'SZFF 15/85 old' has been proved not to be sensible, in either economic or ecological terms.

5 Discussion

In this study, the price difference between different Al-alloys is taken as a criterion for their value as a material for the allocation of the environmental burdens. This type of allocation is definitely preferable to that in which the environmental relevance of a material is directly related to a price, e.g. by estimating the environmental relevance of the recycling step by the price difference between primary material and scrap.

The results of the economic allocation no longer stress the importance of an explicit closed-loop recycling for window frames and the use of a high percentage of recycled material. More realistically, emphasis is laid on a frame construction suitable for recycling aiming to maintain the inherent properties of aluminium at the highest possible level over the life cycle. Therefore, the highest possible separability of the metals in the window scrap is one of the key conditions to optimise the ecological profile of aluminium frames. This already has to be focused during the design of an aluminium window: the renunciation of Zinc die-cast parts and a construction where the fitting bars easily slide out after cutting the corner plates as well as the handle during demolition.

It has to be underlined that an economic allocation is only applied for aluminium as the quantitatively most relevant material. Due to limited time and money, all other materials (in small quantities) have been treated according to the old allocation procedure resulting in different allocation procedures within the same study.

In summary, this economic allocation procedure raises two key questions: "What happens to the materials of a product after its use" and "how can the recyclability of a product be optimised" into the focus of an ecological product design.

To substantiate the assumed relation 'market price – functionality within a techno-economic system – quality' based on several economic disciplines, is subject to further investigation.

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Received: April 14th, 1999
Accepted: November 26th, 1999
Online Publication: December 16th, 1999

Call for Comments

1. The first author is interested in other case studies where market prices are used to allocate the environmental impacts of open-loop recycling materials.
2. The allocation problem related with recycled materials in an open loop can be tackled: a) bottom up, looking only at the recycling process itself or b) top-down, modelling the whole material cascade. The methodology presented in this paper is focusing c) on the product system itself, providing a complete, flexible and scope-oriented approach. Are there any conceptional or methodological restrictions for this "intermediate" approach?
3. The methodological approach is based on the key assumption that looking from the demand side, market prices of *primary and secondary raw materials* (not scrap!) reflect the functionality of a material quality within a techno-economic system. Comments on this assumption are welcome.
4. Not considering qualitative aspects of open-loop recycled materials in the allocation procedure can result in misleading conclusions for ecological product design. Have any practical experiences related to this been made? Have other methodological shortcomings been detected with regard to open-loop recycled materials using LCA for ecological product design?

Comments on these questions or any aspect of this article are welcome at: frank.werner@empa.ch