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MODELLING RECYCLING, ENERGY RECOVERY AND REUSE IN LCA

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ABSTRACT

This paper guides the application of ISO 14044 for closed- and open-loop recycling (including for multi-material products), energy recovery, and reuse/further use, based on the provisions of the “ILCD Handbook – General guide on LCA” [EC 2010] and converted into a quantitative formula for the first time. This “ILCD Recyclability substitution” approach takes into account both the input of recycled material into the product (recycled content) and the quantity and quality of recycled material generated at the end-of-life of the product (recyclability, multi-functionality of the material), via "expansion of the system boundary to avoid allocation". It captures both physical reality and market-based effects.

INTRODUCTION

One of the most widely disputed topics in LCA is the modeling of the end-of-life (EoL) of products, especially open-loop modeling. The suggested approaches differ considerably, leading in many cases to substantially deviating results [NCASI 2012, EC 2010]. Some of the frequently used EoL methods are briefly presented in the following section and extensively discussed in [NCASI 2012]. In relation to recycling, the ISO 14044 standard describes two technical situations: closed-loop product systems and open-loop product systems [ISO 14044:2006]. However, often the distinction is unclear and in most cases true closed loop situations do not exist - a joint, consistent approach is beneficial.

Drawing on the wealth of previously suggested and tested approaches, the ILCD Handbook’s General guide for LCA [EC 2010] presents in chapter 14.5 an integrated “Recyclability substitution” approach and gives specific provisions for EoL modeling in line with the ISO 14044 hierarchy to solve cases of multi-functionality. No formula had been provided in the ILCD Handbook for this approach, other than the formula to model allocation cases ([EC, 2010], chapter 14.4) that is however the subordinate choice in the ISO hierarchy.

METHODS

The cut-off method (100/0) considers that environmental impacts of a product should be directly assigned only to the product that causes them. Hence, the primary material burden is assigned to the life cycle burden for the first product [Nicholson et al. 2009]. It accounts for the environmental impacts at the time they occur: if a product is made e.g. of primary metal, the environmental impacts of primary metal production are attributed to this product. Avoided burdens - in case the metal in the product is recycled when its service life ends – are not accounted for, discouraging design for good recyclability.

The 50/50 method distributes the burdens of virgin material production and waste treatment to the first and last products in equal proportions [Ekvall 1994], without considering however the specific causes for material loss at design or end-of-life treatment.

In the Substitution method (0/100), the environmental burdens of avoided primary production are credited for the amount of recyclate that is produced at the end-of- life of a product. The use of recycled materials is not considered [Ekvall 1994], hence discouraged.

The ILCD Recyclability substitution method captures the actual, physical consequences of using recycled materials in a product and allows to account for benefits and impacts due to EoL processes (e.g. recycling, landfilling, produced recyclate etc.). This includes the downcycling effects on recyclate quantity and quality (i.e. changes in inherent properties of materials) and also energy recovery [EC 2010]. It can, in fact, also capture upcycling. The impacts (E) can be calculated as the sum of four components: E = Production + Recycling + Disposal – Credits (or impacts). The formula for this method reads as follows (for parameter definitions see Table 1 and the poster for more details):

$$E = (E_{Pu}*C_P + E_{Pu}*C_R*P_{Su}/P_{Pu}) + (E_{Rg}*R_g + E_{Rg2}*R_{g2}) + E_D*(R_g - S_g + Wg) - (E_{Pu}*S_g*P_{Sg}/P_{Pu} + E_{Pg2}*S_{g2}*P_{Sg2}/P_{Pg2})$$

RESULTS

The ILCD Recyclability substitution formula is illustrated with an exemplary case-study: a polyethylene (PE) chair. Due to restrictions on the article’s length, results related to other approaches can be presented only in the poster; please contact authors to receive a copy.

Table 1 shows the results of different settings of recycled content and recyclability at a given degree of downcycling (represented by the ratio of the market prices of secondary material to primary material), and referring to the impact category “Climate change” (no ‘real’ data, but methodological demonstration only).

DISCUSSION

The results of Table 1 show that the ILCD Recyclability substitution formula rewards both the provision of recyclable products at the EoL (recyclability) and the use of the recyclates (recycled content), depending on what is more relevant in the analysed case: Whenever the market price for the recyclate is high, close to that of the primary material, the market is readily absorbing more recyclates, i.e. there is a real benefit to provide more recyclate as it avoids to provide these materials from primary production. In this setting, the loss of material at the product’s end-of-life is discouraged - lost material is modeled as additional primary material production plus waste deposit efforts for the lost material.

Table 1. Results of the illustration of the ILCD Recyclability substitution formula to an exemplary case in five scenarios, and using electricity production next to material recycling to illustrate multiple recycling/recovery/reuses of a material. Common parameters (white), varied parameters (blue), results (green).

Parameter / LC-step	**Para-meter in formula**	**Base case (1)**	**Increase recycla-bility (2)**	**Increase recycled content (3)**	**Increase recycled content and recycla-bility (4)**	**Increase recycla-bility to high quality recyclate (5)**	**Unit**
Primary PE	E_{pu}	2	2	2	2	2	Impact/kg produced
Electricity grid mix	E_{Pg2}	0,15	0,15	0,15	0,15	0,15	Impact/MJ produced
PE recycling process	E_{rg}	0,05	0,05	0,05	0,05	0,1	Impact/kg treated
Waste-to-energy plant	E_{Rg2}	0,01	0,01	0,01	0,01	0,01	Impact/kg treated
Sanitary landfill	E_{D}	0,01	0,01	0,01	0,01	0,01	Impact/kg disposed
Electricity price from waste-to-energy	P_{Sg2}	0,005	0,005	0,005	0,005	0,005	Euro/MJ
Electricity grid mix price	P_{Pg2}	0,005	0,005	0,005	0,005	0,005	Euro/MJ
Primary PE content	C_{P}	1	1	0,2	0,2	1	Share
Seconary PE content	C_{R}	0	0	0,8	0,8	0	Share
PE mix control value		1	1	1	1	1	Share
Recycling to sec. PE	R_{g}	0,2	0,8	0,2	0,8	0,8	Share
Produced sec. PE (consid. losses)	S_{g}	0,18	0,72	0,18	0,72	0,72	Share
Energy recovery	R_{g2}	0,8	0,2	0,8	0,2	0,2	Share
Primary PE price	P_{Pu}	0,9	0,9	0,9	0,9	0,9	Euro/kg
Used sec. PE price	P_{Su}	0,14	0,14	0,14	0,14	0,14	Euro/kg
Gen. sec. PE price	P_{Sg}	0,14	0,14	0,14	0,14	0,8	Euro/kg
Electricity produced from waste	S_{g2}	*3,2*	*0,8*	*3,2*	*0,8*	*0,8*	*MJ/kg analysed material*
Waste landfilled	W_{g}	*0,02*	*0,08*	*0,02*	*0,08*	*0,08*	*kg/kg analysed material*
PE-chair mat production	*Production*	*2,00*	*2,00*	*0,65*	*0,65*	*2,00*	*Impact*
PE chair recycling/en. recovery efforts	*Recycling/ recovery*	*0,018*	*0,042*	*0,018*	*0,042*	*0,082*	*Impact*
PE chair waste disposal	*Disposal*	*0,000*	*0,002*	*0,000*	*0,002*	*0,002*	*Impact*
PE chair credit	*Credit/mali*	*0,54*	*0,34*	*0,54*	*0,34*	*1,40*	*Impact*
PE-chair EoL inventory	***E (Final results)***	***1,48***	***1,70***	***0,13***	***0,35***	***0,68***	***Impact/kg***

If the material is kept in the loop, it is only handed over to the next user (or in other words, it is temporary "stored" in the product): in the extreme case of 100% recycling at EoL, only the burdens due to the recycling processes have to be inventoried. On the other hand, when there is a lack of use/demand for the recyclates - indicated by a low price for the recyclate compared to the primary material price - stimulation is needed to use a higher recycled content. In this case, the production of additional low quality recyclate will not solve the problem of lack of it's uses and more recycling can even increase the overall impact (Scenario

2). Products that are better designed to be recycled at the EoL and/or use of better recycling technologies that are effectively resulting in higher quality recyclates, are however encouraged (Scen. 5), as well as is the use of low quality recyclates as input material (Scen. 3). Note that the benefit of energy recovery from the incineration of not recycled materials is included in all scenarios. This yields a self-adapting, balanced methodology and formula. Starting from the Base case (Scen. 1) with 0% recycled content and low recyclability, all interim cases are continuously and smoothly calculated (e.g. Scen. 4 with both increased recycled content and recyclability, however to a low quality recyclate, and less material incineration at EoL). The formula can be applied also to multi-material products with one formula per material (or using an expanded formula).

CONCLUSIONS

This article illustrates the ILCD Recyclability substitution approach, summarized in a reference formula, to model the whole range of possible EoL and other waste situations, including open- und closed loop recycling, energy recovery (and analogously reuse and further use), which are methodologically all the same. Importantly, the formula is practical, as no information is needed on subsequent uses or previous uses of the secondary material; type of materials, recycled content, obtained recyclate amount / material losses at the EoL, and market prices are sufficient. The approach is recommended for use in LCA studies that refer to product-level LCA and Ecodesign-type studies, e.g. in the Situation A (micro-level decision support) and C1 (accounting) of the ILCD Handbook, i.e. the vast majority of cases. The method should be further tested for various materials and cases for a representative range of products.

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