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Reconciling recycling at production stage and end of life stage in EN 15804: the case of metal construction products

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Abstract. With the current political focus on resource efficiency and circular economy, the consideration of all recycling aspects in LCA is becoming increasingly important, especially for metal products which are already recycled for many decades. For such purpose, a complementary module, the so-called Module D, was developed in EN15804 to report the additional environmental aspects resulting from the end of life stage. The metal industry and many LCA practitioners have already used this module for many years. This module D as well as module C (end of life stage) are now mandatory in the agreed amendments to EN15804 that will be published in 2019. This paper explains the methodology used by the metal industry to calculate modules A, C & D for a metal sheet in the light of the equation to be included in the amended EN15804. The calculation is then applied to 3 theoretical examples. Finally, the paper provides guidance on using LCI datasets developed by the steel and aluminium sectors. The collaborating authors have prepared this paper under the auspices of the METALS FOR BUILDINGS alliance that has been established to ensure reliable information on the sustainability of metal building products is available to policy makers and practitioners in sustainability appraisal policies and systems.

1. Introduction

Considering the growing concern regarding resource efficiency and the circular economy, recycling is seen as key enabler to move to a more sustainable European Union. In 2015, the European Commission adopted an ambitious Circular Economy Action Plan [1], which includes measures that will help stimulate Europe's transition towards a circular economy, boost global competitiveness, foster sustainable economic growth and generate new jobs. This action plan has been completed in 2018 by the publication of a circular economy package which includes a Monitoring Framework on progress towards a circular economy at EU and national level.

The waste framework directive [2] [3] is also targeting the building sector in a significant way, since article 11 requires that 70% of EU demolition waste shall be treated beyond 2020. Construction

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and Demolition Waste (CDW) represents about 30% of the waste flow produced in Europe. Hence, developing a legislation promoting good practices for construction and demolition waste is essential.

As part of its initiative of the single market for green products, the European Commission launched in 2013, the Product Environmental Footprint initiative which aims to harmonise the methodology of assessing environmental performances of products. This PEF methodology was tested during the pilot phase 2013-2018 and it enters now the transition phase where its potential transfer to product policies will be assessed. In particular for the building sector, the European Commission identified the need for closer alignment of CENTC350 standards to the PEF approach before they could be referred to in product policy. The amendment of EN15804, which defines the core rules for environmental product declarations, was a key milestone in this alignment process. The future amended EN 15804 will require calculation of end of life stage and environmental aspects of reuse, recycling and recovery in the context of the circular economy.

In the coming years, the Construction Product Regulation [4] will require in addition to technical information also environmental information related to building products when Basic Work Requirement 7 addressing the "sustainable use of natural resources" will be implemented in harmonised European standards.

All these legal and market developments show that it is of prime importance to properly consider the recycling aspects of building products when assessing life cycle environmental impacts.

2. Metals in buildings: key enabler to circularity

Metals are used in the building and construction sector for structures, reinforcements, cladding, roofing, window frames, plumbing, heating equipment and many other applications. Due to their high strength and high stiffness, metals can bear high loads, be used to reinforce other materials or can span great distances, allowing design freedom. Metal building products are weatherproof, seismic proof, corrosion resistant and immune to UV rays, ensuring a long service life. Most often, metal building products will satisfy the service life of the building itself.

In addition to their technical properties, metal products have also a unique characteristic which is their ability to be efficiently and economically reused or recycled without altering their properties. Already, today, more than 95% of the metal products used in buildings are collected at end-of-life. As an example, a study [5] performed on several demolition sites in Europe has demonstrated that more than 96% of the aluminium-content of these buildings was selectively collected and sent to recycling facilities. A survey carried out among UK demolition contractors [6] has shown that 99% of steel sections are recycled or reused.

High economic value is the main driver for the systematic dismantling, collection and recycling of metal products. As metal recycling provides energy savings of between 60% and 95% compared to primary production [7][8][16], depending on the metal and the metal-bearing product, metal recycling creates a win-win situation for both the environment and the economy.

3. Recycling in LCA and metals products

Today, two contrasting approaches are generally used to tackle recycling aspects: the recycled content approach [100:0] and the end of life recycling approach [0:100].

On one hand, the recycled content approach [100:0] uses a cut-off approach, which only considers the recycled material in the mass fraction of the product issued from recycling. This approach neglects the recycling performances of the product at the end of its life stage. Even though the end of life recycling rate of metal building products is usually high, e.g. around 90%-95%, the average recycled content in metal products does not reach such a level on a global scale. In reality, the recycled content is currently limited by the scrap availability which is the bottle neck of the metal supply from recycled sources. The growth in the use of metals over many years, and the fact that metal building products have a service life of decades, creates a shortage of available metal scrap that has to be supplemented using primary metals to satisfy demand. As an example, the crude steel production in Europe for the year 2017 [9], excluding imports, was 168,1 million tonnes, from which about 93,35 million tonnes were coming from scrap, i.e. from recycling. This shows that on average about 55% of the steel supply comes from recycled steel scrap. Thus, the recycled content metric alone is not adequate to reflect and integrate the recycling performances of metal products in an EPD.

On the other hand, the End-of-Life (EoL) recycling approach [0:100] considers the recycling rate of the studied product as the relevant parameter for tackling the environmental aspects of recycling. For metal products, the recycling rate corresponds to the actual amount of metals obtained from recycling with the amount of metal initially available within the product. The metal industry considers that this end of life recycling approach is the most relevant for metal products in order to maximise and preserve metal availability for future generations as explained in the common Metals Declaration on Recycling [10], published in 2006. This end of life recycling approach is also accepted in the scientific community as UNEP [11] and ILCD [12]. Under PEF, the circular footprint formula considers a contribution of the end of life recycling parameter for metals which is four times more relevant than the recycled content. This ratio demonstrates the higher relevance of the recycling rate metric for metals.

4. Recycling in EN15804: the hybrid approach

The cut-off approach was chosen for the Module A (production), Module B (use) and Module C (End of life stage) of EN15804 [13] meaning that the recycling benefits of building products at end of life cannot be reported in those modules. An additional module, the so-called 'module D', was therefore needed for transparently reporting the additional benefits which result from the recycling or energy recovery at the end of life of the building product. For closed material loop recycling, as in the case of metals, Module D avoids any double crediting or counting since only the net benefits of recycling are reported based on the net flow, i.e. the secondary material exiting the system boundary at the end of life minus the secondary material already considered at the production stage. Module D is not restricted to metal scrap, as it allows reporting the environmental aspects from the net flow resulting from any secondary material or secondary fuel entering and exiting the product system boundary. Description of an exemplative metal sheet case

Fig.1 gives an example of one possible scenario for a metal sheet. It provides the various flows of scrap, metal semi-finished product and product as well as the main processes included in the system boundaries of the various modules. In this example, it is assumed that the unit of analysis is 1 kg of metal sheet with a recycled content of 40%, i.e. 0,4 kg of metal sheet came from recycling, while the recycling rate at end of life corresponds to 90%, i.e. 0,9 kg of recycled metal is produced at end of life. In such a case, Module D shall calculate the environmental benefits resulting from the production of 0,5 kg of recycled metal, i.e. the net difference between both recycled quantities. The next sections explain how the equation reported in Annex D of the new EN15804 shall be interpreted and used to reflect this example and the associated flow sheet.

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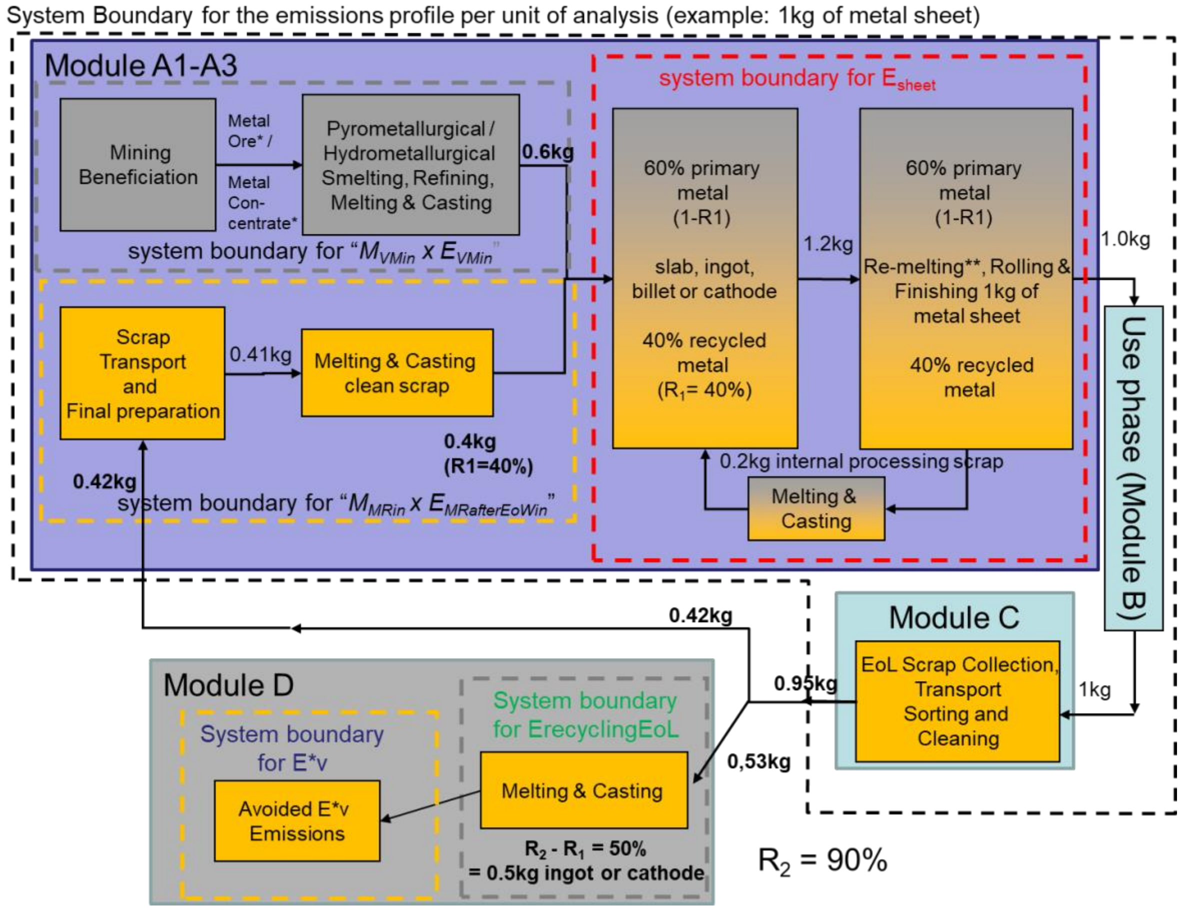

Fig. 1: Illustrative example of a flow diagram for a metal sheet

4.1. Module A1-A3

The applicable formula for the calculation of the emissions and resources consumed related to material resources and energy per unit of analysis for module A is the following:

$$e_{module\ A} = e_{PE} + M_{VM\ in} \cdot E_{VM\ in} + M_{MR\ in} \cdot E_{MR\ after\ EoW\ in} + M_{ER\ in} \cdot E_{ER\ after\ EoW\ in}$$

Where the first term covers the impacts related to primary energy inputs, the second term covers the impacts related to material primary inputs; the third term covers the impacts related to recovered material (recycled and reused) inputs from previous products and the last term covers the impacts related to use of secondary fuels. All terms are calculated per unit of analysis. For metal products, the second and third terms are the 2 most relevant ones.

$M_{MR\ in}$ represents the metal scrap input to the product system at the production stage. In our example, it corresponds to 0,42 kg of metal scrap entering the production stage. After a possible final cleaning and treatment operation, this scrap flow is melted, purified and casted in order to produce a metal ingot. These operations generate small metal losses so that the mass of the recycled ingot is slightly lower than the mass of metal scrap entering the system, i.e. 0,4 kg of recycled ingot in the example. This recycled ingot then needs to be converted into a metal sheet. Hence, "$M_{MR\ in} \cdot E_{MR\ after\ EoW\ in}$" shall cover the specific emissions and resources for producing 0,4 kg of metal sheet issued from recycling. Similarly, "$M_{VM\ in} \cdot E_{VM\ in}$" represents the specific emissions and resources for producing 0,6 kg of metal sheet issued from primary resources.

In practice, the point of substitution, i.e. the location in the production chain where recycled metal substitutes primary metal, is usually at the ingot level or cathode level for the specific case of copper [16]. Hence, often, the LCI datasets developed by the metal industry cover the primary processes or recycling processes up to the ingot level. The manufacturing of the metal sheet from the ingot can then be covered either by a separate LCI dataset (i.e. see aluminium LCI datasets) or aggregated with the ingot production (see steel LCI datasets). In the case of separate LCI datasets, the equation for "Module A1-A3" can be adapted for metal sheet as follows:

$$e_{module\ A} = (1 - R_1) \cdot E_v + R_1 \cdot E_{recycled} + E_{sheet}$$ where:

- R_1 percentage of recycled content of the metal sheet, i.e. fraction of metal issued from recycling
- E_v specific emissions and resources consumed per unit of analysis arising from acquisition and pre-processing of primary metal in the production of the metal ingot or cathode.
- $E_{recycled}$ specific emissions and resources consumed per unit of analysis arising from sorted metal scrap recycling of the previous system into metal ingot or cathode.
- E_{sheet} specific emissions and resources consumed per unit of analysis arising from the transformation of the metal ingot/cathode into the metal sheet.

For the module A1-A3 calculation, 60% of the metal supply is issued from primary metal and 40% from recycling. Hence, the equation can be simplified as follows for the exemplative case.

$$e_{module\ A} = 0{,}6 \cdot E_v + 0{,}4 \cdot E_{recycled} + E_{sheet}$$

The sheet manufacturing from the metal ingot generates some internal scrap which is re-melted but does not increase the recycled content in the LCA model of the overall product, since the recycled content has already been 'fixed' in the slab production process, and the subsequent scrap generated is an internal flow in the overall product system model.

4.2. Module C

The applicable formula for the calculation of the emissions and resources consumed per unit of analysis for module C is the following:

$$e_{module\ C} = M_{MR\ out} \cdot E_{MR\ before\ EoW\ out} + M_{ER\ out} \cdot E_{ER\ before\ EoW\ out} + M_{INC\ out} \cdot E_{INC} + M_{LF} \cdot E_{LF}$$

For metal sheets, the first term is the most significant since it is almost entirely collected and directed to recycling. At end of life, metal sheets are dismantled and specifically collected for recycling. These operations take place under module C1. The collected metal sheet is directed to specialised companies for shredding and sorting (module C3). In the context of EN15804, it can be considered as most appropriate that sorted metal scrap leave the system boundary and are addressed in Module D. It should be noted that there is no full harmonisation among the European countries regarding the application of the "End of Waste" status to metal scrap. Hence, from a legal perspective, the official "end of waste" status may be located at a different point in the recycling value chain.

In our exemplative case, it will be assumed that 99% of the metal sheet is collected and directed to the scrap preparation treatment from which 0,95 kg of sorted scrap is generated and directed for recycling. Hence, 0,95 kg of sorted scrap exits the product system from module C3. Only a tiny fraction can end up in landfilling from the scrap preparation operations.

4.3. Module D

As described in section 6.4.3.3 of EN15804, Module D aims at assessing the benefits and loads resulting from the net flow of secondary fuels or materials exiting the product system. The environmental aspects of these flows are assessed through system expansion using the so-called "substitution methodology" or "avoided impact" methodology. In such methodology, the secondary material needs to be processed up to the point of functional equivalence where substitution of primary material takes place. In the case of metal sheet, the point of equivalence is the ingot or the cathode for copper. Hence, module D calculation needs to consider on one side the burdens of the recycling processes up to the ingot or cathode level while the benefits are calculated by the burdens of primary metal which is effectively saved. If needed, a correction factor may be applied when full substitution cannot take place, i.e. when properties are not maintained through recycling.

For metal sheet, the applicable formula for the calculation of the loads and benefits beyond the system boundary per unit of output calculated for each output flow leaving the system boundary can be restricted to Module D1 related to secondary materials for recycling: For the metal sheet case, only one metal is considered. Hence the indice "i" is not necessary. A as result, the equation can be simplified as follows:

$$e_{module\ D1} = (M_{MR\ out} - M_{MR\ in}) \left(E_{MR\ after\ EoW\ out} - E_{VMSub\ out.} \cdot \frac{Q_{R\ out}}{Q_{Sub}} \right)$$

- "$M_{MR\ out}$" is the quantity of sorted scrap exiting the product system, i.e. 0,95 kg in the example.
- "$M_{MR\ in}$" is the quantity of sorted scrap entering product system, i.e. 0,42 kg in the example.
- "$M_{MR\ out} - M_{MR\ in}$" represents the net quantity of sorted scrap generated by the product system, i.e. 0,53 kg of scrap.
- $E_{MR\ after\ EoW\ out}$ corresponds to the specific emissions and resources arising from the recycling at end of life of the sorted scrap up to the ingot. For the metal sheet case, it will be called $E_{RecyclingEoL}$.
- $E_{VMSub\ out}$ is specific emissions and resources consumed per unit of analysis arising from acquisition and pre-processing of the primary material from cradle to the ingot. For the metal sheet case, it will be called E_v^*.
- $\frac{Q_{R\ out}}{Q_{Sub}}$ is the quality factor between recycled ingot and primary ingot. For metals, the properties are restored through re-melting.. In the building market, only a limited number of metal alloys or grades are used. In addition, collection and scrap preparation routes from end of life metal building products are well developed. These routes generate high quality scrap with low level of contamination. Hence, it can be assumed that recycled metal is of equivalent quality as the primary metal, i.e. that the quality factor is equal to one.

For the metal sheet case, the net quantity of scrap can be substituted by the difference between the recycled metal at end of life and the recycled metal content at production, i.e. (R2 - R1) *1kg = (0,9 – 0,4)*1kg =0,5 kg under the condition that $E_{RecyclingEoL}$ and E_v^* use the mass of produced ingot or cathode as the reference flow, i.e. the process output, and not the scrap input as a reference flow. This assumption will be used for the 3 fictitious examples so that the equation is simplified as follows:

$$e_{module\ D1} = (R_2 - R_1) \cdot (E_{recyclingEoL} - E_v^*) = 0{,}5 \cdot (E_{recyclinEoL} - E_v^*)$$

5. Calculation for 3 theoretical examples

The first example (Product "P1") considers the metal sheet case as described in the previous section, using a recycled content of 40% and an end of life recycling rate of 90%. The second example (Product "P2") considers a generic product, not necessarily a metal product, which is produced mostly from secondary materials (R_1 =80%) but which is not efficiently recycled in closed loop at end of life, i.e. R_2 = 40%. Finally, the third example (Product "P3") corresponds to a product made 80% of recycled material and which is recycled at 80% at end of life according to two scenarios, either in pure closed loop (scenario A) or in an open loop recycling with downcycling (scenario B).

Table I reports fictitious figures expressed in "Units of Indicator" [UoI] for the various processes listed for the previous simplified equations as well as the corresponding results for Module A1-A3, Module C and Module D. For Module C, only the sub-modules C3 and C4 play a differentiating role in the 2 scenarios of P3. Hence, only these 2 sub-modules are addressed in Table I

Table 1: equation parameters and [Unit of Indicators] for the 3 theoretical product examples

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<table>
<tr><th rowspan="2">Parameters and process</th><th colspan="4">Module A</th><th colspan="2">Module C</th><th colspan="3">Module D</th></tr>
<tr><th>R_1</th><th>E_v</th><th>$E_{recycled}$</th><th>E_{sheet}</th><th>C3</th><th>C4</th><th>R_2</th><th>$E_{recylingEoL}$</th><th>E_v^*</th></tr>
<tr><td>Unit</td><td>%</td><td>[UoI]</td><td>[UoI]</td><td>[UoI]</td><td>[UoI]</td><td>[UoI]</td><td>%</td><td>[UoI]</td><td>[UoI]</td></tr>
<tr><td>P1</td><td>40%</td><td>40</td><td>10</td><td>5</td><td>2</td><td>1</td><td>90%</td><td>10</td><td>40</td></tr>
<tr><td>P2</td><td>80%</td><td>40</td><td>10</td><td>5</td><td>2</td><td>3</td><td>40%</td><td>10</td><td>40</td></tr>
<tr><td>P3 - scenario A - closed loop</td><td>80%</td><td>30</td><td>20</td><td>0</td><td>4</td><td>1</td><td>80%</td><td>20</td><td>30</td></tr>
<tr><td>P3 - scenario B - open loop</td><td>80%</td><td>30</td><td>20</td><td>0</td><td>2</td><td>1</td><td>80%</td><td>5</td><td>10</td></tr>
<tr><th>Results</th><th colspan="4">Module A</th><th colspan="2">Module C</th><th colspan="3">Module D</th></tr>
<tr><td>Equation</td><td colspan="4">$(1-R_1).E_v+R_1.E_{recycled}+E_{sheet}$</td><td colspan="2">C3+C4</td><td colspan="3">$(R_2-R_1)\cdot(E_{recyclingEoL} - E_v^*)$</td></tr>
<tr><td>Unit</td><td colspan="4">[UoI]</td><td colspan="2">[UoI]</td><td colspan="3">[UoI]</td></tr>
<tr><td>P1</td><td colspan="4">33</td><td colspan="2">3</td><td colspan="3">-15</td></tr>
<tr><td>P2</td><td colspan="4">21</td><td colspan="2">5</td><td colspan="3">12</td></tr>
<tr><td>P3 - scenario A</td><td colspan="4" rowspan="3">22</td><td colspan="2">5</td><td colspan="3">0</td></tr>
<tr><td>P3 - scenario B-1*</td><td colspan="2" rowspan="2">3</td><td colspan="3">-4</td></tr>
<tr><td>P3 - scenario B-2**</td><td colspan="3">4</td></tr>
</table>

*R_1 is not considered for the net flow calculation of module D as allowed in EN15804

**R_1 is considered for the net flow calculation of module D as recommended in ISO14044

P1 - Assuming values of 40 [UoI] for the primary production of 1 kg of ingot, 10 [UoI] for the production of recycled ingot from sorted scrap and 5 [UoI] for the transformation of 1 kg of ingot into sheet, the module A equation gives a result of 33 [UoI] for module A1 to A3 for 1 kg of metal sheet. Module C does not contribute significantly to the overall results. It is assumed that the scrap preparation of 0,95 kg of sorted scrap (module C3) contributes for 2 [UoI]. Landfilling contributes for 1 [UoI]. For the calculation of module D, similarly to the production phase, it is assumed that the recycling of sorted end of life scrap into 1 kg of ingot generates 10 [UoI] and the avoided primary production of 1 kg of metal ingot corresponds to 40 [UoI]. This provides a complementary result of -15 [UoI] for Module D reflecting the additional benefits resulting from the end of life recycling.

P2 –The same [UoI] figures are assumed as for P1, except for Module C, for which the contribution of landfilling is higher than for P1 considering the higher fraction going to landfilling. A value of 3 [UoI] is used for the landfilling impact. The Module A calculation provides 21 [UoI]. It is lower than for P1 due to the higher recycled content. The calculation of Module D provides a positive [UoI] due to a negative net flow of secondary materials entering Module D. The consumption of 40 % of recycled material generates then an additional impact of 12 [UoI] for module D.
Comparing P1 and P2 results, P2 appears as a better when using the recycled content approach, i.e. Module A + Module C, providing 26 [UoI] for P2 against 36 [UoI] for P1. However, from a full life cycle perspective which considers as well the additional benefits from end of life, the conclusions are reversed, i.e. 21 [UoI] for P1 against 36 [UoI] for P2. This shows the importance to consider Module D in the product assessment. It should be noted that EN15804 does not allow aggregation of results across modules. Hence, this aggregation is done for the sake of illustration and explanation but is not according to EN15804.

P3- For the sake of simplicity, E_{sheet} is not considered in this example (i.e. E_{sheet} = 0 [UoI]). For the closed loop case (scenario A), it is assumed that $E_{recycled}$ and $E_{recyclingEoL}$ are identical and correspond to 20 [UoI] while E_v and E_v^* are also the same processes and correspond both to 30 [UoI]. For module C3, i.e. preparation for recycling, a figure of 4 [UoI] is assumed.

For the open loop recycling with downcycling (scenario B), it can be assumed that ErecyclingEoL is less impacting than the closed loop case, i.e. a value of 5 [UoI] is used. Similarly, Ev* is also smaller since the substituted primary material is of lower quality/performances in case of downcycling than in case of closed loop recycling. A figure of 10 [UoI] is used for Ev*. For module C3, the preparation for recycling is less demanding than in case of closed loop recycling. Hence, 2 [UoI] is chosen for C3. For Module A, the calculation gives a figure of 22 [UoI]. For Module C, scenario A gives 5 [UoI] while the open loop with downcycling (scenario B) gives 2 [UoI]. Without considering Module D, the results for Modules A and C provide a lower impact to the open loop recycling with downcycling (scenario B) in comparison to the closed loop. In such a case, not considering Module D, will clearly lead to misleading choices which are against the most environmentally sound end of life practices.

In case of closed loop recycling (Scenario A), the module D is equal to 0 [UoI]. In absence of any recycled materials generated or consumed by the product system, a value of 0 [UoI] is indeed calculated for module D. In such a case, there is indeed no discrepancy between the recycled content and the end of recycling rate.

In case of open loop recycling (scenario B), it can be assumed that the secondary materials entering the system are not similar to those exiting the system. Hence, a net flow calculation via a direct deduction does not make sense. In such a case, the current formulation requires to calculate the net flows only for the secondary materials exiting the system. This means that the secondary materials entering the product system can be neglected in the calculation of Module D if its characteristics are significantly different from the characteristics of the secondary materials exiting the product system.

In the case of Scenario B-1, the entering flow of secondary materials has been neglected. This gives a benefit of - 4 [UoI] which results from a double crediting of the recycling benefits from the recycled content at production and from open loop recycling at end of life. From a calculation perspective, this open-loop recycling scenario B1 appears then as the most relevant for reducing the overall impact of the product life cycle while in reality, it is not the case, since the closed loop recycling provides better environmental results. The current lack of requirements to address all entering flows of secondary materials and fuels generate then results which can be misleading and which create discrimination against closed loop recycling vs. open loop.

In the case of scenario B-2, the calculation is corrected and the benefits from the recycled content are considered, leading to a result to +4 [UoI] for module D reflecting the effective downcycling at end of life. In other words, the product system consumes high quality secondary materials at production stage without generating them back at end of life. This second calculation shall be systematically used for Module D to properly reflect the additional contribution (benefits or burdens) of the end of life stage to the product life cycle assessment and to avoid misleading calculation wrongly promoting downcycling. The equation should then be adapted accordingly in any future revision of EN 15804.

6. Using datasets developed by the metal sector

Table 2 reports the LCI datasets which can be used in the context of EN15804 and building applications. Further explanations are then given for the 2 metal cases: Aluminium and steel.

Table 2. Aluminium and steel LCI datasets for use in EN15804

Module	Formula in EN 15804	Metal datasets corresponding to EN 15804 formula terms assuming 1kg sheet product	
		Aluminium	Steel
A	$M_{VM\ in} \cdot E_{VM\ in}$ + $M_{MR\ in} \cdot E_{MR\ after\ EoW\ in}$	R_1 x [wrought ingot from pre-consumer scrap or clean post-consumer scrap] + (1-R_1) x [primary ingot produced (or used) in Europe - cradle to gate] + [sheet produced from wrought ingot]	Aggregated cradle to gate LCI for 1kg steel sheet containing recycled and primary steel e.g. "Cold rolled coil" or "Continuous Hot Dip Galvanised coil"
D	$(M_{MR\ out} - M_{MR\ in}) \left(E_{MR\ after\ EoW\ out} - E_{VMSub\ out} \cdot \frac{Q_{R\ out}}{Q_{Sub}}\right)$	(R_2-R_1) * ([ingot from post-consumer scrap] - [primary ingot produced (or used) in Europe - cradle to gate])	$(M_{MR\ out} - M_{MR\ in})$ * [Value of scrap LCI], i.e. LCI result using 100% scrap based EAF slab minus theoretical 100% primary slab.

6.1. Aluminium sheet

Every 5 years, *European Aluminium* develops average datasets representative for the European production or market. The latest datasets published in Feb 2018 refer to data collected for the year 2015 [8]. The datasets listed in Table 2 are included in this report, i.e.

- [primary ingot produced in Europe - cradle to gate] (A) corresponds to the production of 1 tonne of ingot from primary aluminium, i.e. from bauxite mining up to the sawn aluminium ingot ready for delivery. This dataset includes all the environmental aspects of the various process steps and raw materials used to deliver 1 tonne of sawn primary ingot produced by the European smelters.
- [primary ingot used in Europe - cradle to gate] (B) is similar to the previous dataset but considers as well the primary aluminium which is imported into Europe and which represent 49% of the primary aluminium used in Europe in 2015. Global data from the International Aluminium institute [14] have been used for modelling the primary aluminium produced outside Europe.

  If the use of average European LCI datasets is appropriate, these two datasets can be used for assessing E_v or E_v^*. The choice between both datasets should then be based on the sourcing of the primary aluminium. In case of evidence of domestic European production, the dataset (A) should be used. If not, the dataset (B) should be used.
- [sheet produced from wrought ingot] This dataset corresponds to the transformation of a sawn aluminium ingot into a sheet ready for delivery to the user. This dataset includes the recycling of the scrap and chips generated during the sheet production stage and corresponds to the production of 1 tonne of aluminium sheet. This dataset can be used to assess E_{sheet}
- [wrought ingot from pre-consumer scrap or clean post-consumer scrap] corresponds to the production of 1 tonne of recycled wrought ingot, i.e. slabs or billet, from process scrap or clean sorted post-consumer aluminium scrap like big aluminium pieces in the building sector or aluminium beverage cans collected through specific collection networks.
- [ingot from post-consumer scrap] corresponds to the production of 1 tonne of casting ingot from pre- or post-consumer scrap

6.2. Steel sheet

The World Steel Association, *worldsteel*, provide global and regional average data for up to 16 different semi-finished steel products [15]. The *worldsteel* modelling approach employs vertical averaging incorporating the slab and sheet production emissions specific to the individual product

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supply chains. For this reason, it is not necessary to split the data into slab and sheet, since the datasets already correspond to the result of:

$$(1 - R_1) \cdot E_v + R_1 \cdot \ E_{recycled} + E_{sheet}$$

The construction related sheet LCI products available, depending on the region, include: plate, hot rolled coil, cold rolled coil, hot dip galvanised, organic coated coil, and welded tube. Long products, such as sections and rebar are also available, similarly including further rolling and processing as for sheet production. The value for R1 is specific to the product supply chain and steel production process and provided in the datasets as a scrap input flow (external scrap). This excludes scrap recycled internally within the product supply chain and any re-melting losses, and so is no equivalent to the recycled content as such. The scrap input flow can be used to calculate the net scrap flow to avoid double accounting in Module D.

Due to the fact that all steel slab production includes some scrap, it is necessary to make a theoretical 100% primary slab without any scrap input. This has been modelled and calculated by worldsteel and is used with the corresponding 100% secondary slab to calculate the net environmental benefit of recycling 1kg of pre and post-consumer scrap, called the ['Value of scrap' LCI]. A yield factor is used to account for any scrap input or output that is lost during the re-melting due to the presence of non-target material in the scrap and metallic re-melting losses in e.g. fume dust. This means that the EN 15804 formula for Module D can be directly applied since on one side $(M_{MR\ out} - M_{MR\ in})$ corresponds to the next flow of scrap generated by the product system and on the other side $\left(E_{MR\ after\ EoW\ out} - E_{VMSub\ out.} \cdot \frac{Q_{R\ out}}{Q_{Sub}}\right)$ corresponds to ['Value of scrap' LCI],

i.e. = $yield \cdot \left(100\%\ secondary\ slab - 100\%\ theoretical\ primary\ slab \cdot \frac{1}{1}\right)$

Module D = $(M_{MR\ out} - M_{MR\ in})$ * ['Value of scrap' LCI]

7. Conclusion

In 2016, the European Commission requested an amendment to EN 15804 in order to ensure a convergence with the Environmental Footprint methodology, and in particular to make mandatory Modules C and D, which address the end of life stage. This development will bring renewed focus on recycling aspects of construction materials, which is an important aspect if the construction industry is to reduce waste, increase resource efficiency and become more circular. This paper shows the importance of considering the quantity and quality of recycling at end of life, and why the only focus on recycled content is insufficient. End of life recycling is not only relevant for metals, due to the increasing demand for materials and a limited supply of available secondary materials, but also other materials. The new proposed formula for Module D in the future amended EN 15804 has been applied to a series of 3 examples, to demonstrate the way both recycled content and end of life recycling are reconciled in a hybrid approach, thus ensuring a full picture of circularity over the lifecycle. The paper also highlights potential pitfalls in the interpretation of the wording of EN 15804, and so users of the standards should play particular attention to situations where net losses of valuable material resources from the system occur, or where changes in the quality of materials take place. This is important in order to avoiding double accounting recycling benefits at the beginning and end of the lifecycle, especially in open loop recycling situations. The paper also offers guidance to users in applying the available steel or aluminium average LCI datasets for the calculation of Modules A1-A3 and Module D.

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