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The practical use of module D in a building case study: assumptions, limitations and methodological issues

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Abstract. According to the EN 15804 and EN 15978, a material or building life cycle consists of three major life cycle stages or so-called modules: Production and Construction (module A), Use (module B) and End-of-life (module C). Potential benefits and loads occurring beyond the building's life cycle as a result of recycling, reuse or energy recovery can be declared in an additional module D. As part of the upcoming amendment of the EN 15804 a formula was developed to facilitate the calculation of module D. This paper provides a critical discussion on the practical use of module D. First of all, the development of the formula revealed specific methodological issues, such as the unequal approach to closed and open loop recycling. Secondly, the consideration of module D in a Belgian building LCA case study provided insights in the different methodological choices, interpretations, and assumptions related to the calculation of module D. This concerns for example the calculation of net output flows of secondary materials, modelling of avoided primary production, definition of the point of functional equivalence, efficiency of incineration, etc. Aspects that are not clearly specified in the standard and therefore can be open to interpretation are illustrated with concrete examples from the building case study. Where possible, recommendations for a harmonized approach are made. In any way, the results from the case study analysis reveal that the methodological choices can have a significant effect on the results and that module D results should therefore be considered with care.

1. Introduction

Probably one of the most controversial issues in building Life Cycle Analysis (LCA) is how to allocate impacts and benefits from recycling and energy recovery of materials at end-of life between the system (building (material) life cycle) that generates the secondary resources (output) and the one that uses them as input. According to the European standards for the environmental evaluation of buildings (EN 15978 [1]) and the environmental product declaration of building products (EN 15804 [2]), the system boundary between both systems shall be set where materials/fuels have reached their end-of-waste (EOW) state. This state is reached when the criteria derived from the European Waste Framework Directive are met (e.g. the recovered material is commonly used for specific purposes and fulfils the technical requirements for that purpose, a market demand exists, and its use will not lead to overall adverse environmental or human health impacts) [3]. All impacts occurring prior to EOW are attributed to the first product system and all impacts occurring after EOW are attributed to the next product system.

Consequently, the first life cycle benefits from the fact that the (demolition) waste is valorized as it does not have to carry the impact of waste disposal (landfill, incineration). The subsequent life cycle benefits from using secondary materials/fuels as it does not have to carry the impact from primary



material extraction/production (which is fully attributed to the first life cycle), but only the impact from transport and further processing of the secondary materials after EOW.

Often the highest benefit from secondary material valorization is the avoided impact from substituted primary production. The reason why the European standards keep these avoided impacts outside the system boundaries of the system that generates the secondary output flow is that the uncertainty concerning the potentially avoided impact is very high, given the long life span of a building (e.g. energy mixes and production processes are very likely to evolve, and the demand for recycled products at the time of demolition is uncertain). Moreover, it would be unfair to credit “highly uncertain potential” benefits that will occur in a distant future against consumption today [4].

Nevertheless, information on the potential benefits from recycling, reuse and/or energy recovery of materials after the building life cycle could stimulate planning and design choices that facilitate greater valorization potential at the end of the use period. Therefore, the European standards provide rules to calculate this information and declare it as supplementary information “beyond” the building life cycle, in the so-called module D (modules A, B, and C represent the production stage, the use stage, and the end-of life stages of a building, respectively). Until now, this module was optional and therefore often not included in building (material) LCA. However, with the proposed amendment of the EN 15804+A1+prA2 [5] module D will very likely become mandatory.

2. Module D: the theory

Module D represents the potential benefits and loads from “net” output flows of materials for recycling (e.g. secondary materials), reuse or energy recovery (e.g. secondary fuels), but also from energy exported to the outside of the building system boundaries. The latter can be energy produced during waste disposal (incineration or landfill) of construction materials or energy generated on the building site (during the use-stage) that is exported for other uses (e.g. electricity produced by photovoltaic panels on the roof that is exported to the grid).

The potential benefits reported in module D represent the avoided impact from primary material production/extraction (which is substituted by the secondary materials) and avoided generation of primary energy (heat and/or electricity production substituted by the use of secondary fuels or energy exported from waste disposal and on-site energy production). The potential loads relate to the recycling and recovery processes occurring from beyond the system boundary (point of EOW) up to the point of functional equivalence, where the secondary material, fuel or exported energy substitutes primary production. If the output flow does not reach the functional equivalence of the substituted process a justified value-correction factor has to be applied. Both benefits and loads shall be calculated based on current average technology and practice. If information on current practice is lacking, a conservative approach shall be used [2].

The “net” output flow of materials for recycling or energy recovery represents the difference between the output flows of a specific secondary material or fuel leaving the system at EOW and the amount of this secondary material or fuel initially used as input during the production stage.

3. Objectives and methodology

The objective of the present paper is to provide a critical discussion on the practical implementation of module D based on the insights gained from (1) a Belgian building LCA case study including module D, (2) discussions with LCA experts, and (3) the translation of module D into a formulae as part of the latest amendment proposal of EN 15804+A1+prA2 [5]. The main issues handled in this paper relate to the identification of the point of functional equivalency, the calculation of net output flows and the potential benefits from avoided (primary) production.

3.1. Case study

The environmental performance of a 4-level multi-residential building, with 25 living units and a total net floor area of about 2000 m², was calculated using LCA. Different load bearing structures and material combinations were tested (e.g. wood-skeleton, concrete, cross-laminated timber, and sand-lime bricks)

in order to evaluate how and whether results would be influenced by the construction mode. The LCA was performed with SimaPro, using generic data (ecoinvent v3.4, cut-off by classification), and end-of-life scenario's representative for Belgium [6]. More information on the case study, the results on the relative importance of module D on building level (compared to other life cycle modules) and the main materials contributing to module D are presented in a separate publication [7].

An additional goal of the case study was to get a better insight into the practical implementation of module D. For example, can the standard be applied univocally or is it open for interpretation? Is all necessary data readily available to perform the calculations? What kind of hypotheses need to be made? The main methodological issues that were identified through this practical implementation are discussed in the next sections.

4. Results: issues related to the calculation of module D

4.1. Net output flows

In module D, benefits and loads are calculated only for the resulting net output flows (= output minus input) of secondary materials or fuels. The reasoning behind this approach is that secondary materials used as input to the production stage (module A) do not have to carry the impact from primary material extraction/production (which is attributed to the previous life cycle). Consequently, as benefits are already taken into account in the production stage, they cannot be considered again in module D. Moreover, this approach intends to prevent that output flows of secondary materials would be considered to substitute primary materials in a next product system, when the next product system (which is supposed to be identical to the one that generated the waste) is already (partly) using secondary materials in reality. The principle of calculating net output flows is illustrated in **Figure 1**. Case 1 represents the “basic” situation where the secondary material on the input side and the output side are the same (e.g. steel scrap), and the quantity of secondary material at the output side is larger than at the input side.

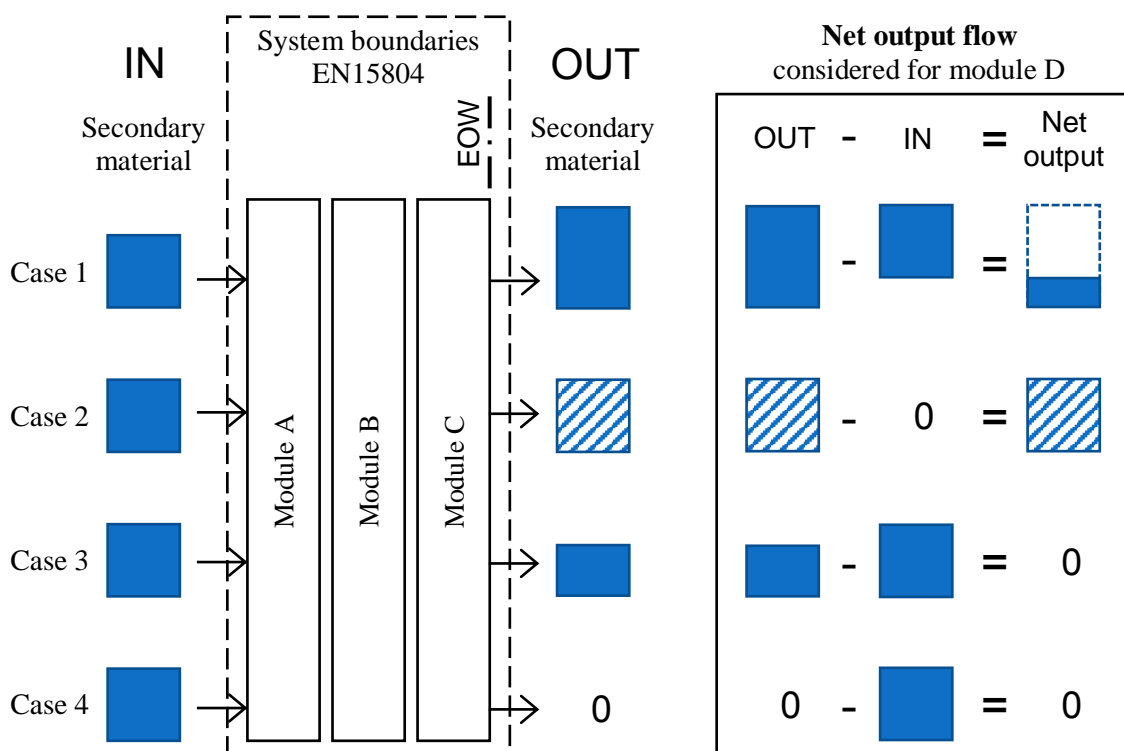


Figure 1. Conceptual representation for the determination of the net output flows depending on the type and quantity of secondary material at input and output side.

This approach for calculating net output flows can however only be applied in closed loop systems. Therefore it leads to an unequal treatment between open and closed loop recycling. Indeed, in open loop systems the secondary materials used as input (e.g. glass cullets for the production of glass wool insulation) are different from the secondary materials exiting the system (e.g. glass wool fibers that can be used as reinforcement for the production of composite materials). Therefore, the amount of secondary materials used as input cannot be subtracted from the output for the calculation of the net output flow (see **Figure 1**, case 2). Consequently, if the impact of the substituted primary material is of the same order of magnitude in open and closed loop recycling, this approach will tend to favor open loop recycling. Indeed, in open loop recycling the amount of net output flow considered for the calculation of module D will be higher since it is not reduced by the input flow of secondary materials.

Apart from clear open and closed loop recycling, there are also many cases where the calculation is open for interpretation. For example, crushed bricks are used as input for the production of a specific type of hollow bricks sold on the Belgian market. At end-of-life those bricks will probably follow the Belgian default scenario for inert waste, namely 95% of recycling into secondary granulates (e.g. for road construction). The nature of the input and output flows are essentially the same (crushed bricks). So in practice a net output flow could be calculated. Nevertheless, the substituted materials (clay in the first system and aggregates in the second system) are different. To our interpretation this should be treated as an open loop (as for case 2).

Another question that can be asked concerning the calculation of the net output flow is what to do in cases where the input of secondary materials is higher than the output (see **Figure 1**, case 3) and therefore the net output flow is negative? One approach would be to multiply the negative flow with the substituted impact from primary production, and therefore report net impacts rather than benefits in module D. However, materials with a recycled content that are disposed of at the end-of-life (e.g. landfill or incineration) could also be considered to have a negative output flow (output = 0, input > 0), but they do not have to report potential impacts from “not” recycling in module D (**Figure 1**, case 4). Moreover, negative output flows are in fact net input flows, while module D is intended to report net output flows of secondary materials (not net input). Therefore, the authors suggest that only positive output flows should be reported in module D.

Table 1. Loads and benefits reported in module D for 1 kg of concrete depending on the point of functional equivalence

Point of functional equivalence	Impacts reported in module D	Benefits reported in Mmodule D
OPTION 1 After crushing (recycling plant)	▪ None	▪ 1 kg limestone, crushed
OPTION 2 At (road) construction site	<ul style="list-style-type: none"> ▪ No primary resource ▪ Transport of secondary aggregates to construction site (<i>30 kgkm by 16ton lorry, EURO5</i>) 	<ul style="list-style-type: none"> ▪ 1 kg Limestone, crushed ▪ Transport of primary aggregates to construction site (<i>100 kgkm by 16ton lorry, EURO 5</i>)
OPTION 3 At end-product level (gate of concrete factory)	<ul style="list-style-type: none"> ▪ $1/X^a$ m³ of concrete made with <ul style="list-style-type: none"> recycled aggregates (impact of the aggregates = 0 unless some additional crushing is needed) 385 kg cement /m³ concrete 2.11 kg plasticizer /m³ concrete ▪ Transport of secondary aggregates to construction site (<i>0 kgkm as recycling plant = concrete plant</i>) 	<ul style="list-style-type: none"> ▪ $1/X^a$ m³ of concrete made with <ul style="list-style-type: none"> limestone crushed 380 kg cement /m³ concrete 2.08 kg plasticizer /m³ concrete ▪ Transport of crushed limestone to concrete factory (<i>100 kgkm by 16 ton lorry, EURO5</i>)

^a With X = mass of secondary aggregates /m³ of concrete

4.2. Point of functional equivalence

Potential loads and benefits reported in module D are calculated from EOW up to the point of functional equivalence where the secondary material/fuel/energy substitutes primary production [2]. Therefore, the determination of the point of the functional equivalence can have a major impact on the loads and benefits reported in module D. A first example is the case of inert materials (e.g. concrete). In Belgium, about 95% of concrete from demolition waste is recycled as aggregates, mainly for use in road construction. EOW is reached after crushing of the demolition waste (at the recycling plant). Once the concrete is crushed it can be used as infill for road construction instead of primary aggregates. For module D, the primary aggregates will thus represent the substituted primary production. However, the determination of the point of functional equivalence is open for discussion. A first option is to set it at the gate of the recycling plant. A second option is to set it at the construction site in order to account for the difference in transport between primary and recycled aggregates (**Table 1**). Indeed, there are many recycling plants in Belgium but only very few quarries. Therefore, primary aggregates are typically transported over larger distances than secondary aggregates. Consequently, although recycled and primary aggregates are technically “equivalent” for use in road construction, one could assume that they are only functionally equivalent once they have reached the new (road) construction site (see option2).

On the other hand, a third option is that the secondary aggregates are to be used as aggregates in concrete (instead of infill in roadbed construction). In this case the point of functional equivalence should be set at end-product level in order to account for variations in concrete mix (e.g. extra cement and superplasticizer) due to the (partial) replacement of primary aggregates by secondary aggregates (see Option 3 in **Table 1**). As can be seen from **Figure 2** the impact from the assumed additional use

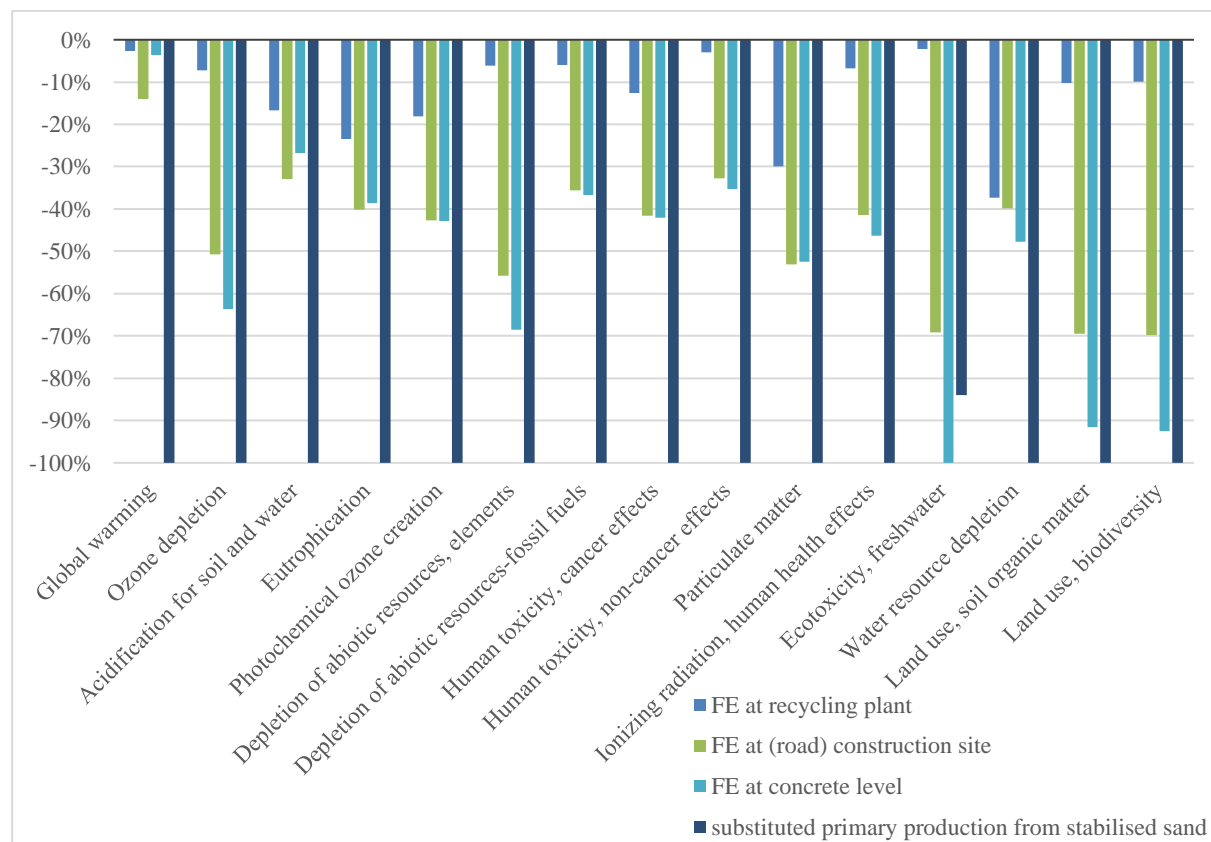


Figure 2. Impacts (net benefits) reported in Module D of concrete when recycled aggregates substitute crushed limestone and the point of functional equivalence (FE) is set at different levels, or when recycled aggregates substitute stabilised sand (MMG v1.05 LCIA model). [8]

of cement leads to a significantly lower net benefit for the impact category Global Warming Potential. Moreover, if the transport of secondary and primary aggregates were equally important, this option could even lead to a net impact instead of a benefit in module D.

Similarly, the case study showed that the outcome of module D of steel products varies significantly depending on whether the point of functional equivalence is set at intermediate product level (sorted steel scrap substitutes pig iron) or at product level (secondary steel substitutes primary steel) in order to account for the lower energy needed to produce steel from steel scrap (with an Electric Arc Furnace (EAF)) than from pig iron (with a Blast Oxygen Furnace (BOF)). Indeed, for most impact categories considered (**Figure 3**) the net benefits reported in module D are higher when the point of functional equivalence is set at the gate of the steel making process. These results are related to the lower energy demand from secondary steel production and in the case of Abiotic Depletion Potential - Elements the possibility to take into account not only the avoided impact from pig iron, but also from alloying elements contained in the steel. However, as the EAF and BOF use different energy mixes (EAF uses mainly electricity, BOF mainly fossil fuels) and produce different types of residues, substituting BOF production by EAF also leads to net impacts for some of the impact categories considered (Ionising Radiation, Ecotoxicity, Human Toxicity, Water Resource Depletion). The small net impacts observed for Abiotic Depletion Potential - Elements for the case where the functional equivalent is set at pig iron level can be explained by the fact that the impact from copper used for the sorting plant is higher than the reported benefit from the substituted pig iron. When the functional equivalent is set at steel level this impact is overruled by the additional benefit from the avoided production of alloying elements (e.g. molybdenite and ferrochromium).

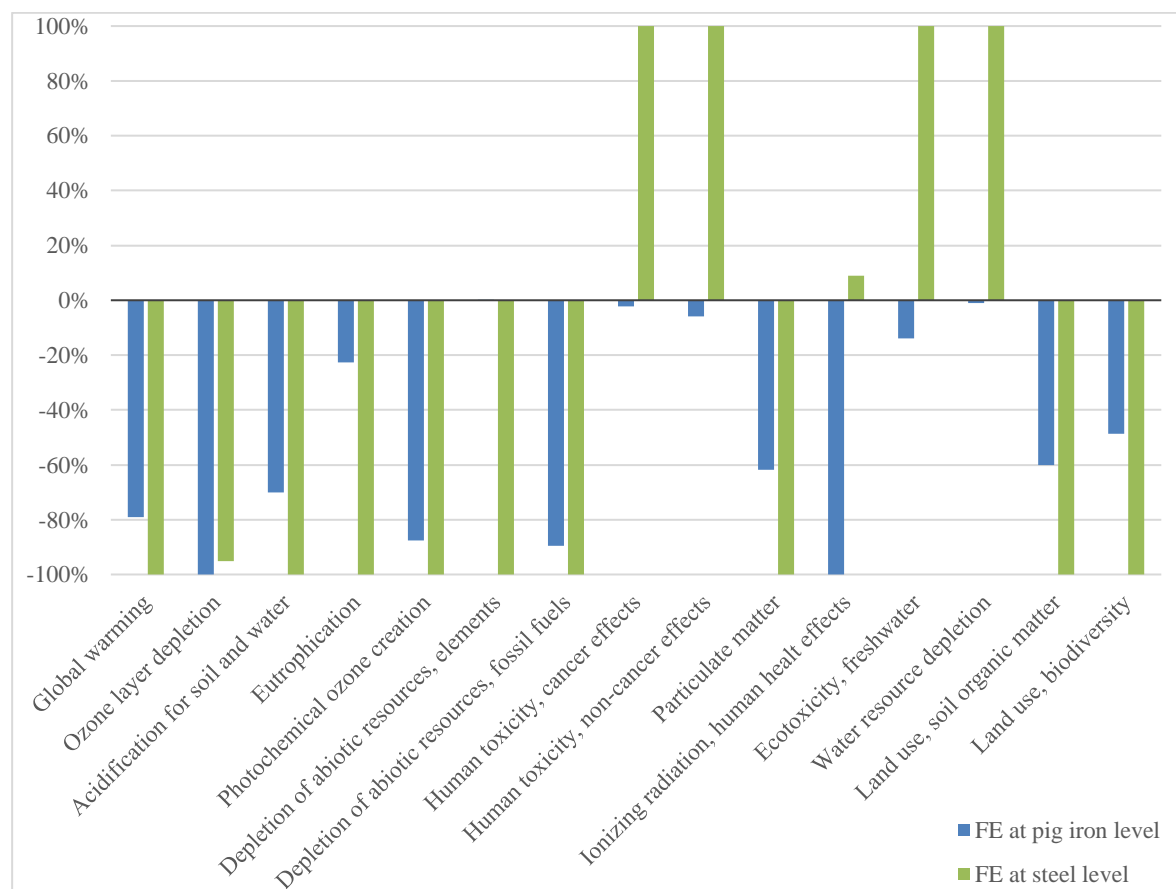


Figure 3. Comparison of module D for 1 kg low alloyed steel with functional equivalency (FE) set before (pig iron level) or after the steel making process (MMG v1.05 LCIA model). [8]

4.3. Avoided “primary” production

The primary production substituted by the use of secondary materials, fuels or exported energy determines which benefits are reported in module D. However, this primary production cannot always be determined univocally: it can be unclear what is actually substituted when the secondary material becomes part of common (usual) practice, the production process based on solely primary resources can be inexistent or the material might be recycled or reused unintentionally as an impurity.

A first example concerns secondary concrete aggregates. The net benefits calculated for module D of concrete in the previous section assumed that the secondary aggregates would substitute primary aggregates. However, in Belgian practice secondary aggregates are always used as infill for road constructions. So, there is some uncertainty related to what they really substitute. Some study suggests that secondary aggregates do not substitute primary aggregates in road construction but stabilized sand [9]. In that case the avoided impact (benefit) reported in module D would no longer be crushed limestone, but a mix of 90% sand and 10% cement. Seen the high impact of cement compared to aggregates, this hypothesis would result in significantly higher net benefits in module D (**Figure 2**).

In some cases, the use of secondary materials affects the production process, or 100% primary production does not exist and therefore needs to be determined artificially. This second example is related to “primary” steel production, where some steel scrap is still used in the BOF. Consequently, the life cycle inventory data of the BOF process have to be manipulated to obtain the (theoretical) impact from a 100% primary production [10]. This could be overcome by allowing the calculation of module D for closed loop systems to be based on the total output flow of secondary materials, provided that the assumed substituted production represents the current average production (with input of secondary materials). Loads reported in module D would in that case also be calculated for the full output flow and in practice this would lead to equivalent results as the net output flow approach with substituted primary production.

A third example concerns the material gypsum installed on inert material (e.g. bricks or concrete). According to the default Belgian scenarios [6], at EOL the gypsum will be crushed together with the inert materials to produce recycled aggregates. Therefore, one could argue that the gypsum (on inert material) substitutes primary aggregates. However, in reality the gypsum reduces the quality of the recycled aggregates and is only tolerated to a certain extent. Consequently, gypsum cannot be considered to be functionally equivalent to primary aggregates and to the author’s opinion no benefit from substituted production should be reported in module D.

Finally, the calculation of module D becomes more complex when a waste fraction knows multiple applications (e.g. glass can be recycled as beads for sand-blasting, as secondary aggregates for roadworks, or used as input for glass wool production) and therefore multiple recycling routes have to be modelled and assumptions have to be made concerning the weight for each route. Moreover, although the standard only mentions the benefits from substituted “primary” production, the secondary materials can also substitute other secondary materials in an open loop system (e.g. recycled flat glass cannot only replace sand but also recycled consumption glass in the production of new glass products). Therefore, the benefits reported in module D can also represent the avoided impact from secondary production. This approach is reflected in the formula for module D included in the proposed amendment of the standard [5], which mentions the substituted primary material “or substituted average input material if primary material is not used”.

5. Conclusions

“Module D recognises the “design for reuse, recycling and recovery” concept for buildings by indicating the potential benefits of avoided future use of primary materials and fuels while taking into account the loads associated with the recycling and recovery processes beyond the buildings life cycle” [2]. Until now the declaration of module D is optional so there is little experience with the calculation of module D at product or building level. Based on experiences gained from a Belgian building case study including module D as well as from the translation of module D into a formula as part of the EN 15804 amendment, several methodological issues were identified related to the practical implementation and

significance of module D. In order to avoid double counting, the potential loads and benefits from secondary materials and fuels are only reported for the net output flows. However, as net output flows can only be calculated for closed loop recycling this leads to an unequal treatment between open and closed loop systems. Results from the study also indicate that assumptions regarding the point of functional equivalence and substituted (primary) production can have a significant impact on the results reported in module D. In addition, the substituted primary production may be difficult to assess when the use of secondary materials is part of the common practice and their use influences the production process. Moreover, in an open loop system, secondary materials/fuels can not only substitute primary materials/fuels but also other secondary materials/fuels.

Uncertainty concerning the potentially avoided impact is not only high because of all underlying assumptions, but also because energy mixes, production processes and demand for secondary materials/fuels are very likely to evolve over the long life span of the building. Consequently, results from module D should always (and especially in comparative LCA) be used with care and interpreted together with the underlying scenarios. Also, in order to avoid unequal treatment within product groups, product technical committees should be encouraged to provide, whenever possible, default scenarios for module D or at least guidance for the identification of the point of end-of-waste, the functional equivalence, and the substituted production.

References

- [1] CEN 2011 *EN 15978:2011 - Sustainability of construction works - Assessment of environmental performance of buildings - Calculation method*
- [2] CEN 2013 *EN 15804:2012+A1 Sustainability of construction works - Environmental product declaration - Core rules for the product category of construction products*
- [3] European Parliament and Council 2008 Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain directives (Waste framework directive) *Off. J. Eur. Union - L312* 3–30
- [4] International Energy Agency 2004 *Life Cycle assessment methods for buildings, Annex 31, Energy-related environmental impact of buildings*
- [5] CEN 2018 *EN 15804:2012+A1:2013/prA2:2018 - Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products*
- [6] NBN 2017 *NBN / DTD B 08-001 Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products - National supplement to NBN EN 15804+A1:2014*
- [7] Delem L and Wastiels L Module D in the building life cycle: significance based on a case study analysis *Central Europe towards sustainable building 2019*
- [8] De Nocker L and Debacker W 2018 Annex: Monetisation of the MMG method [update 2017] *OVAM, Mechelen*
- [9] CE Delft 2016 *Hoogwaardige recycling gevat in een beleidsformule en een multicyclis-LCA-methodiek*
- [10] World Steel Association 2011 *Life Cycle assessment methodology report*