IOP Conference Series: Earth and Environmental Science

Module D in the Building Life Cycle: Significance Based on a Case Study Analysis

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Abstract. According to the European standard for the assessment of the environmental performance of buildings (EN 15978), potential benefits and loads beyond the building's life cycle as a consequence of recycling, reuse or energy recovery of building materials can be declared in module D. However, in practice module D is rarely included in LCA studies as it requires an optional calculation step and information at the product level (from EPD's according to EN 15804) is often missing. By means of a case study analysis, considering five building cases with varying types of loadbearing structures, the present study evaluates the relative importance of module D on building level and provides a better insight in the main materials contributing to module D. The results show that based on the current Belgian end-of-life scenario's the contribution of module D can be significant at the building level (representing up to 50 % of the total life cycle impact). This contribution varies more according to the LCIA indicator considered than to the building variant. In terms of the materials, the metals represent the main contributors to module D.

1. Context and objectives

Building materials that can be recycled, reused or used for energy recovery at end-of-life are considered potential resources for future use. However, how can we account for these "potential" benefits in building LCA? The EN 15978 [1] provides calculation rules for the assessment of the environmental performance of buildings based on a life cycle approach. According to this standard, the building life cycle can be divided into the following major life cycle stages/modules: Production (module A), Use (module B) and end-of-life (module C). In case of materials for recycling, reuse or energy recovery the boundary between the building's EOL stage (module C) and the next product system is set where the materials 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) [2]. All potential benefits (e.g. from avoided primary production) and loads occurring beyond the system boundaries (after EOW state) can be reported in an optional module: module D.

According to the second amendment of EN 15804 [3] the declaration of module D will become mandatory on product level. So, in the future the information will be available for evaluations on building level. Meanwhile, little tools on building level already include module D. Existing studies indicate that module D can be significant relative to the building life cycle impact; however, they were limited to one renovation case with intensive metal use and did not consider the benefits from energy recovery (only from recycling) [4][5].

Therefore the objective of the present study was to get an insight in the relative importance of module D on building level and in the main materials contributing to module D, based on a case study considering various new building variants (material combinations) and a broad set of impact categories. Additionally, the case study also served to identify difficulties, data-gaps and methodological issues related to the calculation of module D, but these will be discussed in separate publications.

2. Case study

The object of the case study is a 4-level apartment building with 25 living units and a total net floor area of about 2000 m². Based on its floor plan five alternatives with varying loadbearing structures were defined: (1) sand-lime brick, (2) hollow concrete blocks, (3) concrete skeleton with hollow concrete blocks as infill, (4) wood-skeleton and (5) cross-laminated timber (CLT). The foundations, windows, doors, and stairs are identical for all variants. On the contrary, the floor elements and non-loadbearing inner walls were chosen in function of the structure in order to have realistic cases (e.g. gypsum block inner-walls for variants 1, 2, 3 and light partition walls for variants 4, 5). The finishing materials were kept equal wherever realistic (e.g. same façade coverings for all variants (ETICS and bricks)) but adapted to the structural system when needed (e.g. walls in masonry finished with gypsum plaster, but wood skeleton walls finished with gypsum plaster boards). The main insulation materials are the same for all variants (combination of EPS (outer walls), PUR (flat roof and floor on ground) and mineral wool (wood frames and (acoustical) insulation of walls between apartments)), but their thicknesses were adapted to achieve similar energy performances. Based on Energy Performance of Buildings calculations [6], the estimated yearly energy consumption of each variant is 374 GJ (gas) for heating, 84 GJ (gas) for sanitary warm water production and 7.750 kWh electricity for auxiliaries (furnaces, circulators, ventilation).

3. Methodology

3.1. System boundaries, life cycle inventory, service life, life cycle impact assessment method

The various building variants were modelled in SimaPro using generic data from Ecoinvent v 3.3 (cut-off system model), and gate-to-grave scenario's representative for the Belgian market [7]. The analysis considered module D and following life cycle stages for a building service life of 60 years: production (A1–A3), transport (A4), construction (A5), replacements (B4), operational energy use (B6-restricted to heating, domestic hot water supply and ventilation) and end-of-life (deconstruction (C1), transport (C2), waste processing (C3) and disposal (C4)).

The "material" impact of the technical systems (heating, ventilations, electricity, elevators,…), kitchens and bathrooms were excluded from the analysis (assumed equal for all variants).

The case studies were analysed based on the impact categories required by the EN15978 [1], namely Global Warming (GWP), Ozone Depletion (ODP), Acidification (AP), Euthrophication (EP), Photochemical Ozone Creation (POCP), and Depletion of Abiotic resources elements and fossil fuels (ADPelements, ADPfossil fuels). Those were calculated using the CML-IA baseline (version 3.03) model which was adapted to meet the 2012 version as required by the standard EN 15804+A1 [8]. Moreover, as a larger set of impact categories are envisaged for the next revision of the standard [3], following additional impact categories from ILCD 2011 midpoint method (v1.09, may 2016) were also considered: Particulate Matter (PM), Ecotoxicity Freshwater (EF), Human Toxicity Cancer (HT cancer) and Non-cancer (HT non-cancer), Ionising Radiation Human Health (IR), Land Use Soil Organic Matter (SOM), and Water Scarcity (Water).

Finally, the case studies were analysed using an aggregated score, obtained from the monetarisation of above mentioned impact categories including the additional impact category Land Use Biodiversity (Eco-indicator 99 v6.3 method) [9]. This aggregated indicator (MMG-score) corresponds to the Belgian assessment methodology as used in TOTEM, the Belgian tool to optimize the total environmental impact of materials (www.totem-building.be). For this study version MMG v1.02, April 2017 is used.

3.2. Calculation of module D

Module D takes into account the potential impacts and benefits from “net” output flows of materials for recycling, reuse or energy recovery (i.e. secondary fuels) and avoided energy production from incineration of waste. Table 1 presents the recycling and incineration rates (at end-of-life) of the main materials taken into account for the calculation of module D. The recycled content (needed for the calculation of net output flows) of specific materials were taken from the corresponding Ecoinvent processes. In all cases it was assumed that EOW was reached after the sorting plant, so all impacts occurring prior to sorting are attributed to module C and all impacts and benefits occurring after this point (up to the point of functional equivalence where the secondary material or energy substitutes primary production) were attributed to module D.

Table 1. Main recycling and incineration rates considered for the calculation of module D, including assumptions concerning the avoided primary material production in case of recycling

Waste stream	Incineration	Recycling	Avoided primary material (benefit from recycling)
Inert materials (e.g. bricks, concrete, glass)	-	95%	Crushed limestone for road bed construction.
Chemically impregnated wood	100%	-	-
Clean wood	15%	85%	
Painted wood	85%	15%	Virgin wood particles (for particle board production)
Composite wood products	5%	95%	
Burnable insulation (e.g. EPS, PUR)	95%	-	-
Metals (e.g. reinforcement steel, zinc gutters, steel fire staircase)	-	95%	Point of functional equivalence at intermediate/end product level to account for reduced production energy
PVC (window frames)	45%	45%	Polymerised polyvinyl chloride emulsion.
Cellular concrete	-	30%	Primary sand for production of new cellular concrete
Gypsum (blocks, boards)	-	20%	Natural gypsum
Polyethylene (membranes, pipes)	85%	5%	Polyethylene granulate production

Concerning the incineration of waste, the study assumes that all waste incineration plants have an efficiency for energy recovery lower than 60% and therefore all impacts from waste incineration are allocated to module C4 (disposal), while the benefits from the exported energy (avoided impact from conventional heat and electricity production) are accounted for in module D. Those benefits are calculated according to the formula below. Parameter sets can be found in Table 2.

$$e = LHV * (XER,heat * ESE,heat + XER,elec * ESE,elec)$$

Where: e = benefit reported in module D per kg of waste sent to incineration
LHV = lower heating value of the waste
XER,heat = efficiency for the energy recovery process for heat
XER,elec = efficiency for the energy recovery process for electricity
ESE,heat = specific emissions and resources per MJ substituted energy source for heat production
ESE,elec = specific emissions and resources per MJ substituted current average electricity production

Table 2. Values and assumptions for calculation of benefits related to exported energy from incineration

LHV	Derived from the corresponding ecoinvent incineration processes	
XER, heat	0.2	[7]
XER, elec	0.1	[7]
ESE, heat	Considered substitution: Heat, natural gas, at industrial furnace >100kWh	[7]
ESE, elec	Considered substitution: Belgian electricity mix excluding the impact of network and transmission losses	[7]

4. Results and discussion

4.1. Module D – Relative importance on building level

Table 3 presents the relative importance of module D compared to the total life cycle impact (modules A to C set to 100 %) excluding operational energy (B6) of the various building alternatives and Table 4 its relative importance compared to the total life cycle impact including operational energy (B6). A conditional formatting is applied per building variant in order to study the relative importance of Module D across the impact categories (green represents the highest benefit and red the lowest).

Based on Table 3 and Table 4 various observations can be made. The results show that, depending on the impact category and building variant considered, the relative contribution of module D can be significant. Indeed, it varies between about +45 % and -52 % of the total life cycle impact excluding operational energy and between about +35 % and -48 % of the total life cycle impact including operational energy use.

Table 3. Relative importance of Module D, for each building variant compared to their total life cycle impact excluding operational energy (B6)

Impact category	Sand-lime brick	Hollow concrete block	Concrete skeleton	Wooden skeleton	CLT
GWP	-21%	-23%	-21%	-20%	-24%
ODP	-21%	-22%	-21%	-20%	-27%
AP	-15%	-15%	-12%	-6%	-6%
EP	-42%	-42%	-39%	-30%	-25%
POCP	-27%	-27%	-24%	-14%	-12%
ADPelements	-52%	-52%	-52%	-47%	-45%
ADPfossil	-25%	-26%	-24%	-23%	-28%
HTcancer	17%	18%	16%	9%	8%
HTnon cancer	44%	45%	41%	24%	16%
PM	-18%	-19%	-17%	-13%	-9%
IR	-17%	-17%	-16%	-20%	-36%
Ecotox	-4%	-3%	-4%	-4%	-4%
Water	-14%	-12%	-14%	-34%	-26%
SOM	-13%	-14%	-13%	-11%	-4%
Biodiversity	-23%	-24%	-22%	-12%	-3%
Monetarised score	-8%	-8%	-7%	-9%	-10%

Table 4. Relative importance of Module D, for each building variant compared to their total life cycle impact including operational energy (B6)

Impact category	Sand-lime brick	Hollow concrete block	Concrete skeleton	Wooden skeleton	CLT
GWP	-7%	-7%	-7%	-6%	-7%
ODP	-6%	-6%	-6%	-5%	-7%
AP	-8%	-8%	-7%	-4%	-4%
EP	-30%	-30%	-29%	-21%	-19%
POCP	-14%	-14%	-13%	-8%	-8%
ADPelements	-48%	-48%	-47%	-43%	-41%
ADPfossil	-6%	-6%	-6%	-5%	-7%
HTcancer	15%	15%	14%	8%	7%
HTnon cancer	34%	35%	32%	18%	13%
PM	-14%	-14%	-13%	-11%	-8%
IR	-5%	-5%	-5%	-6%	-13%
Ecotox	-2%	-2%	-3%	-2%	-3%
Water	-9%	-8%	-9%	-16%	-17%
SOM	-8%	-8%	-8%	-8%	-4%
Biodiversity	-16%	-16%	-15%	-11%	-3%
Monetarised score	-4%	-3%	-4%	-4%	-5%

A closer look at the results reveals that the relative contribution of module D varies significantly according to the impact category but much less according to the building variant. For instance, for all building variants, the impact category for which module D represents the highest relative impact is Human Toxicity Cancer and the highest relative benefit is Abiotic Depletion Elements. Between building variants the relative contribution of module D to a specific indicator can be situated within a similar range. One exception can be identified for the CLT building, where module D contributes significantly higher to Ionizing Radiation than in the other building variants (see Table 3), which can be explained by the avoided impact from electricity production resulting from the incineration of wood. In any way, the relative importance of this benefit becomes less important when including the operational energy use (see Table 4).

The results for the Human Toxicity indicators show that module D can results in net 'impacts' rather than benefits (see positive indicator values). As will be discussed in section 4.2, for both indicators, the impact related to the recycling process of steel exceeds by far the benefits related to the other materials contributing to module D.

Finally, for the monetarised single score, module D represents a net benefit of less than 10 % of the total life cycle impact excluding B6 and less than 5 % of the total life cycle impact including operational energy. This relatively low net benefit can be explained by the impact of module D on Human Toxicity Cancer/Non Cancer. Those two impact categories contribute significantly to the monetarised score and therefore reduce the beneficial contribution of other impact categories to the aggregated score (see Figure 1 for the contribution of the different indicators to the monetarised results).

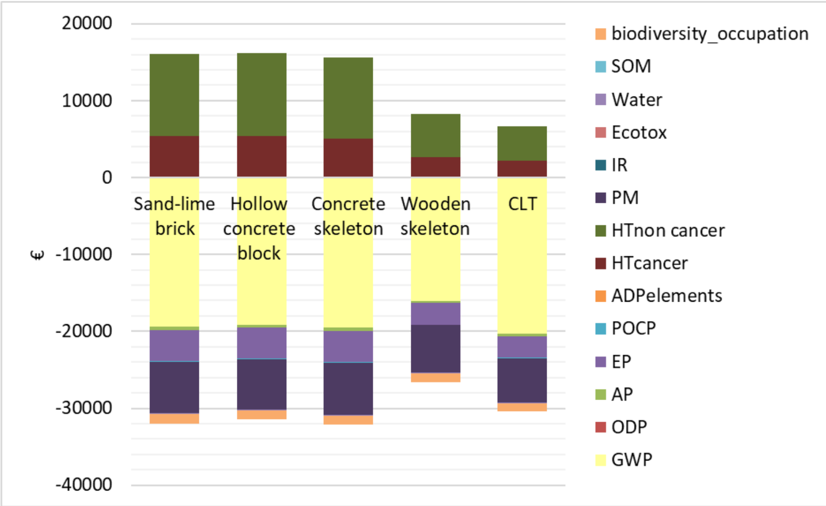

Figure 1. Monetarised results for module D of the various building variants

4.2. Module D – main (material) contributors

Figure 2, Figure 1 and Figure 3 represent respectively the relative contribution of the building materials to module D of the sand lime brick building and the wood skeleton building, and this for the various impact categories considered. Those results indicate that for most impact categories considered (except for Ionising Radiation), the metals contribute significantly to module D of both buildings (although none of them is a steel construction and technical installations are not considered). Concerning the recycling of metals, Figure 2 shows that the recycling of steel results in net impacts for all toxicity indicators and for water resources. This is due to the fact that for steel the point of functional equivalence was set at product level (1kg of steel), to account for the reduced production energy induced by the use of scrap instead of iron ore in the steel production process. Consequently, the impact of recycling corresponds to the production of steel in an Electric Arc Furnace (EAF), using 100 % scrap, and the avoided impact corresponds to the production of virgin steel (from iron ore) in a Basic Oxygen Furnace (BOF). Now, the EAF production uses a completely different energy mix than the BOF route and moreover it produces slags which have a high impact on toxicity (when landfilled).

For the sand lime brick building (Figure 2), the inert materials also contribute significantly to module D (beneficial for all indicators considered). However, this contribution is considerably influenced by the assumed transport distances for primary (100km by truck) and secondary aggregates (30km by truck) to the construction site. Indeed, the benefit resulting from the avoided transport is for all considered impact categories but water depletion at least as important as the benefit resulting from the avoided production of primary aggregates (crushed limestone). Also, even though the mass of inert materials used in the building is about 30 times higher than the total mass of metals in the building, and the recycling rates are equal for inert materials and metals (95 %), the contribution of inert materials to module D is usually lower or similar to the contribution of metals. These insights confirm the findings from previous studies that metals strongly influence the results in module D [4,5].

Based on Figure 3, wood recycling results in net benefits for all indicators considered. The avoided impact from primary wood production contributes mainly to the impact categories Land use SOM, and Land Use Biodiversity (avoided impact of virgin wood extraction) and to a lesser extent to Particulate Matter (avoided impact related to drying of virgin wood with wood furnace). For those indicators, the contribution of module D is in absolute values higher for the wood skeleton building and the CLT building than for the massive building variants. However, as the life cycle impact (for modules A to C) of the wood-based construction modes is generally higher for those specific indicators [10], the relative importance of module D related to the wooden materials remains limited (Table 3).

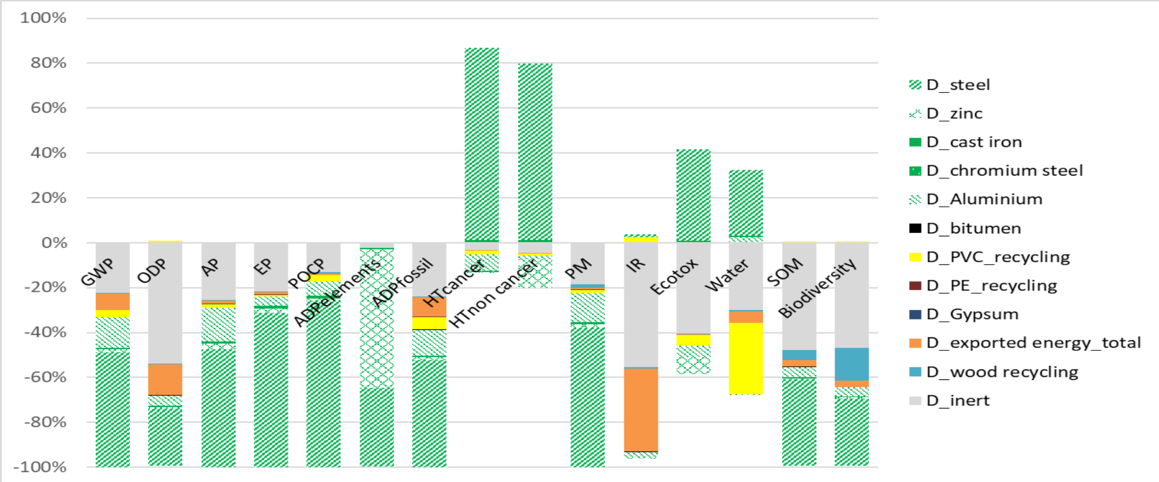

Figure 2. Overview of the main contributors to module D of the sand-lime brick building (1)

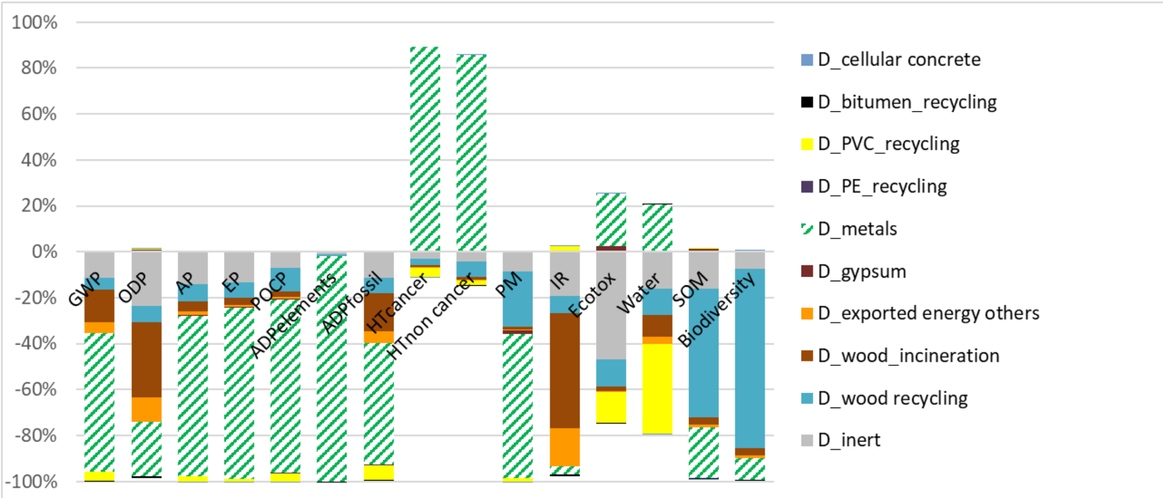

Figure 3. Overview of the main contributors to module D of the wood skeleton building (4) (D_metals represents the sum of module D of zinc, aluminium, (chromium) steel, and cast iron)

Although for the present case study a very conservative approach was taken concerning the efficiency of waste incineration plants, and approximately half of the wood products were sent to recycling, for GWP, ODP, ADP-fossil and especially IR, the net benefit from exported energy from wood incineration is higher than the net benefit from recycling wood. Nevertheless, the relative contribution of module D to those indicators is limited when including the operational energy use of the building (Table 4).

Finally, the recycling of cellular concrete and gypsum blocks led for a certain number of indicators to some net impacts (their relative contribution is however so small that they are almost invisible in the graphs). Indeed, for both materials we assumed that the secondary materials were transported 100 km by truck from the sorting plant to the recycling plant (new cellular concrete/gypsum block factory). As there is only one recycling plant for each material in Belgium, this seems a reasonable distance. On the other hand the avoided impact from primary materials and the corresponding transport was modelled using market processes from ecoinvent. Now, the transport included in those market processes seems lower than the assumed transport for the secondary materials, and for some impact categories the resulting net impact from transport surpasses the avoided impact from primary material production (natural gypsum or sand). This reveals the important influence of the assumptions being made concerning the transport of primary and secondary materials, as well as the data sets available.

5. Conclusions

This study evaluated module D for five building variants of a multi-residential building (with the same lay-out but different material compositions). The evaluation was based on generic data and considered end-of-life scenarios representative of the Belgian market. The results show that for some impact categories (e.g. Human Toxicity, Eutrophication, ADP Elements) module D can be important in comparison to other life cycle modules (A-C). Also, the contribution of module D varies less according to the building variants than to the impact categories considered. Even though no metal structure was considered among the building variants, and technical installations were excluded from the present study, metals and especially steel represented a major contributor to module D. This not only because of the high recycling rates of metals but also because of the high impact of primary steel production which is avoided by recycling. Indeed, the study reveals that it is not necessarily the recyclability (or recycling rate) of the materials that determines the magnitude of the net benefits reported in module D but mainly the impact associated with the avoided primary production.

For some indicators and materials, recycling results in net impacts rather than benefits. In the case of steel, the results showed that, for Human Toxicity, Water depletion and Ecotoxicity the impacts related to secondary steel production (electric arc furnace) outstand the benefits from substituted primary production (basic oxygen furnace). Consequently, as Human Toxicity contributes significantly to the monetarised results (MMG-score), the net benefits reported in module D are relatively small (around 5 %) compared to the monetarised life cycle impact of the building.

Finally, module D requires the definition of several assumptions (e.g. recycling rates and recycled content, transport scenarios for primary and secondary materials, avoided primary production, definition of point of functional equivalence, efficiency of incineration). These can have a significant impact on the results and should therefore be considered with care. Further research and publications will elaborate on these methodological issues.

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