Assessment of the feasibility and potential impact of adding additional ecolabel criteria for global warming impacts of buildings and building materials

Bo P. Weidema, Tina S. Trolle
2.-0 LCA consultants, Aalborg, Denmark
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Preface and acknowledgements

This report presents an assessment of the feasibility and potential impact of adding additional ecolabel criteria for specific building materials or building parts, requiring calculations of the global warming impact for either a part or the entire life cycle of the buildings. The study has been conducted by 2.-0 LCA consultants for Nordic Ecolabelling with financial support from the Nordic Council of Ministers. The project was conducted from July to October 2020.

We wish to thank the interviewed building LCA experts, Harpa Birgisdottir, Martin Erlandsson, Matti Kuittinen, Panu Pasanen, and Jakob Rørbech, as well as the representatives of Nordic Ecolabelling, Heidi Belinda Bugge and Elisabeth Magnus for their helpful cooperation.

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2.-0 LCA consultants, Aalborg, Denmark

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Contents

Abbreviations and acronyms

BIM: Building Information Model
CPR: Construction Products Regulation
EPD: Environmental Product Declaration
GWP: Global Warming Potential
LCA: Life Cycle Assessment
PCR: Product Category Rules
RSL: Reference Service Life

Executive summary

What are the options for Nordic Ecolabelling to support the reduction of global warming from buildings by adding more requirements for specific building materials or building parts, e.g. by requiring calculations of the global warming impact for either a part for the entire life cycle of the buildings? We investigate this question by reviewing the current landscape of life-cycle based standards, methods and tools available for designers and producers of buildings and building materials. We identify a number of ambiguities in the standards that cause inconsistencies in their interpretation and practical implementation, resulting in a limited comparability of results from different databases and tools.

We conclude that the current consistency and comparability of life-cycle based calculations for construction products are insufficient to be the basis for the Nordic Ecolabelling programme to require such calculations as part of their criteria. In spite of this, we identify three areas where ecolabelling criteria would currently be verifiable:

- Requirements on specific construction products with identical functionality, where greenhouse gas emission reductions are clearly verifiable, e.g. when obtained through light-weighting.
- Requirements aiming at increasing recycling, such as design for disassembly and minimum recycling targets specified by material type.
- Requirements to reduce overall material demand over the forecasted service life of the building under well-specified, realistic use scenarios.

It is obviously not the role of the ecolabelling programmes to rectify the current consistency and comparability problems of life-cycle based calculations or the ambiguities in the standards. Nevertheless, to incentivise radical building design changes, it is imperative to seek cooperation with other stakeholders that have similar interests in obtaining consistent and comparable results from life-cycle based calculations, an issue that is not limited to building materials. We recommend a cooperation of stakeholders with the aim of establishing a common open database that:

- Has globally complete system boundaries,
- Links unit processes according to verifiable cause-effect relationships,
- Enforces a strict completeness requirement on the included unit processes, using mass and monetary balancing,
- Includes future scenarios based on realistic and transparent procedures,
- Requires activities, and thus flows, to be clearly specified in time, and
- Requires all flows to be provided with uncertainty.

All of these aims can be seen as supported by the current standards. Once a database with the above specifications has been established, we recommend that Nordic Ecolabelling requires LCA calculations to be performed with data from this database, unless the user can provide improved data.

We recommend that such calculations be required at the whole building level, in a phased approach comparable to that currently applied in the Norwegian FutureBuilt programme. Here, a total of four calculations are required:

- A baseline calculation, following detailed, unambiguous rules,
- The targeted building, where a reduction criterion relative to the baseline building must be met,

- For the completed building, as built,
- For the building after 2 years of operation, with data for realised consumption and transport patterns of users.

An additional calculation is also recommended for the choice of demolition of any pre-existing building and building new versus renovation of the pre-existing building.

1 Project objective and scope

The project objective is "to assess the feasibility and potential impact of adding additional ecolabel criteria for specific building materials or building parts, requiring calculations of the global warming impact for either a part for the entire life cycle of the buildings".

The scope of the project is limited to the general landscape of life-cycle based calculation tools for building materials and building components in the Nordic countries (Denmark, Finland, Iceland, Norway, and Sweden) and does not assess any specific tool in detail. Even though the assessed standards, methods, and tools are applicable to environmental impacts in general, the scope of this project is limited to impacts from greenhouse gases, i.e. climate footprints.

Within the above objective and scope, the project seeks to answer the following questions:

- How well do current Life Cycle Assessment (LCA) calculation tools and their database implementations of different standards and methods:
  - provide consistent and comparable results?
  - provide results that reflect the actual life cycle global warming impacts from the construction?
  - support the identification of areas where ecolabelling criteria would have a verifiable high reduction effect on global warming impact?
  - assist users in fulfilling specific requirements?
- Can Nordic Ecolabelling exploit synergies with the current developing landscape of national and European regulations and certification programmes?

The assessment is based on a dialogue between the team from 2.-0 LCA consultants and selected relevant actors, namely:

- Panu Pasanen, CEO, Bionova Ltd., developers of the tool One Click LCA, a dedicated building LCA software that includes a large number of different standards, who contributes also a global perspective;
- Harpa Birgisdottir, Senior Researcher at the Danish Building Research Institute, developers of the tool LCAByg;
- Martin Erlandsson, PCR moderator for the 'International EPD System' and team leader for the research group 'Sustainable Buildings' at IVL Swedish Environmental Institute, developers of Byggsektorns Miljöberäkningsverktyg;
- Matti Kuittinen, Adjunct Professor at Aalto University and Senior Advisor to the Ministry of the Environment of Finland on LCA in the built environment;
- Jakob Rørbech, Velux Danmark A/S, Team leader for Product Sustainability, Standardisation, and Product regulation.

The dialogue consisted of individual interviews followed by a joint workshop. The resulting recommendations are not an expression of a consensus in this group but the sole responsibility of the team from 2.-0 LCA consultants.

A preliminary draft report was reviewed by Kim Christiansen, kimconsult.dk, who has been involved in standardisation and consulting in Life Cycle Assessment for more than 25 years. The reviewed draft report was delivered to Nordic Ecolabelling by September 7th.

This final report includes revisions based on comments from Nordic Ecolabelling on the draft report.

In the following, we have strived to provide an objective description of the state-of-the-art in Chapter 2 to 7, while leaving the subjective assessment and recommendations to Chapters 8 and 9.

2 Relevant standards and their interpretation

The overall international standards for LCA are ISO 14040:2006 and ISO 14044:2006, where the first provides the framework, while the second includes the specific requirements and guidelines.

ISO 14025 provides additional requirements for the application of LCA for Type III environmental declarations, also known as Environmental Product Declarations (EPDs). In particular, Clause 5.6 of ISO 14025:2010 provides a list of requirements for comparability of EPDs and Clause 8.1 contains requirements on verification of EPDs and LCA data used in EPDs.

ISO 21930:2017 provides additional requirements for the application of LCA for EPDs of construction products. However, in a European context, the European standard EN 15804 (latest version EN 15804:2012+A2:2019) plays this role.

In addition to these LCA standards, the European standards EN 15643 and 15978 address building assessment, where information modules from the LCAs may be used, and vice versa. A nice overview of these standards is provided by BRE (2016).

We have not assessed additional standards at the national level, such as Norwegian NS 3720, which is nevertheless also based on EN 15804.

2.1 Ambiguities in interpretation and its consequences

Completeness of systems and consistency of system boundaries

LCAs and LCA databases for building materials generally lack completeness and mass balancing procedures have not yet become a systematic part of current practice. The requirement of the EN 15804 standard to declare all substitution effects of co-products (secondary material, secondary fuel or recovered energy) in a separate module D, rather than integrating these with the life cycle stages they belong to, makes reporting of recycling unnecessarily complicated and open for different interpretations.

ISO 14044 has a requirement that "decisions regarding the data to be included shall be based on a sensitivity analysis to determine their significance" and furthermore "The deletion of life cycle stages, processes, inputs or outputs is only permitted if it does not significantly change the overall conclusions of the study." The handling of this requirement has been much facilitated by the recent advent of open hybrid IO-LCA databases with global coverage, such as Exiobase. However, only few examples exist of the use of these databases to ensure global completeness and mass balances for LCAs of building materials. Out of the 238 building LCAs analysed by Röck et al. (2020) only 10 were analysed using a hybrid database. There is therefore still a large difference in the level of completeness of different datasets. The completeness level can most easily be checked by simultaneous balancing of mass and monetary flows in and out of the unit processes. However, such balancing procedures have not yet become a systematic part of current practice. The new amendment 2 to 15804 includes a Clause 6.3.8.2 that requires both data completeness and plausibility checks that may include such balances. Although it is not explicitly required to report the results of such balancing procedures, it must be expected that these new requirements will over time lead to more completeness in databases.

EN 15804 requires that the product system be subdivided into modules, each of which shall be reported separately, and not aggregated:

- Modules A1-A3, which are all activities until and including the manufacture of the construction products,
- Module A4, which is the transport from producers to construction sites,
- Module A5, which is the construction or installation process,
- Module B1, which is the use of the installed product during the use stage of the construction,
- Module B2, which is any maintenance of the product during the use stage of the construction,
- Module B3, which is any repair of the product during the use stage of the construction,
- Module B4, which is any replacement of the product during the use stage of the construction,
- Module B5, which is the activities related to the product during any construction refurbishment,
- Module B6, which is the energy use of the product during the use stage of the construction,
- Module B7, which is the water use during the use stage of the construction,
- Module C1, which is the deconstruction of the product from the construction,
- Module C2, which is the transport from construction site to a waste processing or disposal activity,
- Module C3, which is the processing, e.g. recycling, until the product reaches the end-of-waste state
- Module C4, which is the disposal activity for final residues,
- Module D, which is the activities that follow after the product and co-products from any of the previous modules have reached the end-of-waste state, except if the product and co-product has inherent properties that are functionally and temporally equivalent to an input in the product system and therefore can be modelled as such an input resulting in a closed loop, cf. Clause 6.4.3.3 of EN 15804:2012+A2:2019.

A full construction product LCA thus includes all these modules except when empty. However, EPDs after EN 15804:2012+A2:2019 may exclude modules A4, A5 and modules B1 to B7, and under certain conditions be limited to A1-A3.

In the title of Clause 6.3.5.6 of EN 15804:2012+A2:2019, module D is labelled as covering activities "beyond the product system boundary" and it is explicitly stated that "Avoided impacts from allocated co-products shall not be included in Module D. This implies that if all co-products would be allocated, module D would be empty, while for all non-allocated co-products module D "declares potential loads and benefits of secondary material, secondary fuel or recovered energy leaving the product system" (Clause 6.3.5.6 of EN 15804:2012+A2:2019), i.e., corresponding to what ISO 14044 denotes as "expanding the product system to include the additional functions related to the co-products" (Clause 4.3.4.2 of ISO 14044:2006), again excluding the situations of closed loops.

Each of the above modules includes provision and transport of materials, products, energy and water use, losses, waste processing up to the end-of-waste state, and disposal of final residues, the only exception being the substitution effects of co-products (secondary material, secondary fuel or recovered energy) that are declared in module D. Module D may thus include such substitution effects of co-products from all other modules. This is somewhat at odds with the purpose of the "modularity principle", which is described as "easy organisation and expression of data packages throughout the life cycle of the product" (Clause 6.3.5.1 of EN 15804:2012+A2:2019). If wishing to communicate the life cycle impacts of, say, the installation process in module A5, the corresponding substitution effects would have to be extracted from module D before the resulting communication would be complete. This would effectively require module D to be subdivided in as many sub-modules as there are modules A-C to be separately communicated.

Identification of technological and geographical origin of materials and components

The LCA standards (ISO 14044 and EN 15804) are open for different interpretations on how to link unit processes into products systems. For the large majority of building material LCAs and EPDs, products systems have been linked by attributing unit processes to the product systems according to different normative rules, typically as an account of the history of the product. This conflicts with the general agreement in the academic literature that LCAs used for decision-support, such as eco-labels, carbon footprints and environmental product declarations, should rather be linked so that they reflect the consequences of the decision to purchase the product. The two modelling approaches can lead to more than an order of magnitude differences in results when applied to the same product.

ISO 14044 and EN 15804:2012+A2:2019 have little guidance on how to link unit processes into products systems, and this has given rise to two different interpretations of the standards on this point, known as "attributional" and "consequential" approaches to modelling.

In the attributional approach inputs and outputs are attributed to the functional unit of a product system by linking and/or partitioning the unit processes of the system according to a normative rule (Sonnemann & Vigon 2011), "typically as an account of the history of the product" (Clause A.2 of ISO 14040:2006). In practice, the attributional product system is identified by starting from the unit process(es) of the reference flow, tracing each cost item input to the next upstream unit process. The cost for the purchasing activity, is a revenue for the supplying activity. For each activity, a part of the revenue leaks out as wages, taxes, and profits (together known as "value added"). In a closed steady-state system, all the original revenue must eventually leave the system as value added, thus providing a clear delimitation of the unit processes included in the system. In practice, not all attributional models use a single product property, such as monetary value, to trace the flows between unit processes, thus resulting in less well-defined system boundaries (Weidema 2018).

In the consequential approach activities are included in the product system to the extent that they are expected to change as a consequence of a change in demand for the functional unit (Sonnemann & Vigon 2011). Consequential modelling seeks to model the potential environmental consequences of changes resulting from a (potential) decision, or as expressed in Clause A.2 of ISO 14040:2006: “environmental consequences of possible (future) changes between alternative product systems”. This implies modelling marginal or incremental changes, as opposed to the average modelling implied in the attributional approach. For both marginal and incremental modelling, Clause 6.4 of ISO 14049:2012, applies:
“The supplementary processes to be added to the systems must be those that would actually be involved when switching between the analysed systems. To identify this, it is necessary to know:

- whether the production volume of the studied product systems fluctuate in time (in which case different sub-markets with their technologies may be relevant), or the production volume is constant (in which case the base-load marginal is applicable),
- whether (…) the inputs are delivered through an open market, in which case it is also necessary to know:
    - whether any of the processes or technologies supplying the market are constrained (in which case they are not applicable, since their output will not change in spite of changes in demand),
    - which of the unconstrained suppliers/technologies has the highest or lowest production costs and consequently is the marginal supplier/ technology when the demand for the supplementary product is generally decreasing or increasing, respectively.”

A consequential product system thus ensures additionality, i.e., that processes are only included to the extent that they are additional to a baseline without the studied change. In practice, the consequential product system is identified by starting from the unit process(es) of the reference flow, tracing each required product input, physical or monetary, through the marginal supplier(s) of each product, following verifiable cause-effect relationships. In parallel to what occurs in the attributional product system, the revenue generated by the original demand must eventually leave the product system as value added, thus providing a clear delimitation of the processes included in the product system. The processes included are limited to those that react to the change in revenue. The marginal suppliers/technologies can be divided in those that in response to a change in demand for the product will change their production output immediately or within the short-term (i.e. within the current production capacity), and those that in response to an accumulated change in demand for the product will change their production capacity in the long-term. The impacts from the long-term changes in capacity will typically dominate the sum of the short-term and long-term changes.

Both the consequential and the attributional approach to linking are implemented in the ecoinvent 3 database, applying publicly available algorithms on the same set of unit process data.

The ILCD Handbook (JRC-IEA 2010, p. 37) recommends that when LCA is used as decision-support, the LCI model should reflect the consequences of the decision. An EPD can, as expressed by Rydin (2014), “be seen as means for the customer to influence the environmental impact of the purchased products, which gives a requirement on the EPD that it reflects the expected environmental consequences of buying the declared product compared not to buying it", thus making the information from a consequential model the most relevant. For a customer that seeks information with this intention, an environmental label based on attributional modelling may be misleading, as was already pointed out by Weidema (2001). Also Tillman (2010) recognizes that "purchasing inherently involves decisions, and according to the logic described above, information intended to support it, such as eco-labels, carbon footprints and environmental product declarations, should be based on consequential LCA". Yet, most – if not all – actually implemented EPD schemes appear to promote an attributional modelling approach (see e.g. EPD International 2015), and this is also true for the majority of building material EPDs.

The two modelling approaches can lead to very different results when applied to the same product. Weidema (2017a) compares the two implementations in the ecoinvent 3.1 database, showing that 5% of the results had more than an order of magnitude difference, 16% had more than 200% difference, 22% had more than 100% difference, sufficient to be concerned about the use of attributional data for consequential purposes. One of the reasons for the differences is that the consequential modelling specifically includes the marginal suppliers, i.e. the suppliers that currently expand their output when demand on the world market is increasing, e.g. aluminium from China (Beylot 2016), while the attributional modelling would include the specific or average suppliers, even when these are already producing at full capacity and have no options for increasing their capacity.

Calculation rules for co-products recycling

The LCA standards (ISO 14044 and EN 15804) are open for different interpretations on the calculation rules for handling joint production. In the widely used attributional approach, there are different interpretations on when to model recycling as open loop versus closed loop recycling. The two modelling approaches can lead to significantly different results when applied to the same reuse or recycling situations, as exemplified at the end of this sub-section.

In the attributional approach, the substitution effects of co-products are only modelled in situations of closed-loop recycling, i.e. when a dependent co-product from joint production has inherent properties that are functionally and temporally equivalent to an input in the same or another unit process in the same product system. In Clause 4.3.4.3.3 of ISO 14044, closed-loop recycling is described in this way: "A closed-loop allocation procedure applies to closed-loop product systems. It also applies to open-loop product systems where no changes occur in the inherent properties of the recycled material. In such cases, the need for allocation is avoided since the use of secondary material displaces the use of virgin (primary) materials." In Clause 6.4.3.3 of EN 15804:2012+A2:2019, closed-loop recycling is described in this way: "The amount of secondary material output, which is for all practical purposes able to replace one to one the input of secondary material as closed loop is allocated to the product system under study and not to module D." It is unclear if this rule would apply at the building level, so that the secondary material output of one building component could be a closed loop input to another building component of the same building, or whether this should be regarded as open-loop recycling.

In the attributional approach, the tracing "as an account of the history of the product" implies that when closed-loop modelling is not an option, the part of the upstream product system that can be traced to and thus attributed to the product leaving the system must be eliminated from the product system. This elimination procedure is also known as co-product allocation, because the eliminated part of the product system is allocated to the product leaving the system, while the rest is allocated to the product system. In Clause 4.3.4.2 of 14044:2006, the default approach for allocating to the products of joint production is allocation based on their economic value (revenue). In Clause 6.4.3.2 of EN15804:2012+A2:2019 it is instead required that allocation be based on physical properties and "shall respect the main purpose of the processes studied", except when the difference in revenue from the co-products is above 25% in which case the default from 14044:2006 applies, and subsequently an allocation correction shall be introduced as described in Weidema (2018) so that the energy and elementary mass balances (including for biogenic carbon content) are re-established, reflecting the physical flows in and out of the partitioned system. The combination of closed-loop recycling and allocation is somewhat at odds with the "modularity" principle of EN15804:2012+A2:2019, since the extent to which co-products shall be allocated depends on the extent to which they are not used as inputs elsewhere in the product system under study, which can only be determined after the full product system has been modelled.

In the consequential approach, the allocation hierarchy in Clause 4.3.4.2 of ISO 14044:2006 is followed more strictly, so that "expanding the product system to include the additional functions related to the co-products" is applied in situations of both closed-loop recycling and open-loop recycling, i.e., also when a dependent co-product from joint production is produced in amounts exceeding those that can be absorbed as inputs of unit processes within the same product system, as long as the overall market is not saturated. In case of secondary outputs with saturated markets, the product system is instead expanded to include the final disposal of the excess secondary output. This implies that allocation is always avoided. The substitution effects of all co-products from joint production are modelled in the same way, whether used within the product system or within another product system. However, as stated in Clause 6.4.3.3 of EN15804:2012+A2:2019, module D includes only the net substitution effects of secondary products used outside the product system, because the closed-loop recycling part is subtracted.

Besides the above described detailed requirements for attributional allocation, Clause 6.3.5.2 furthermore requires that "Flows leaving the system at the end-of-waste boundary of the product stage (A1-A3) shall be allocated as coproducts", which some practitioners interpret as a requirement to apply an attributional approach. However, the same paragraph continues: "If such a co-product allocation is not possible, other methods may be chosen and shall be justified. Therefore, as a general rule, potential loads or benefits from A1-A3 do not appear in module D." Consequential practitioners instead note that the phrase "as a general rule" has the meaning of "usually; in most cases", thus implying "not always", allowing that such co-product allocation can be declared as "not possible" and substitution applied instead, with several options for justification, e.g.:

- that such allocation would lead to unacceptable cut-offs, and/or unnecessarily deviating from modelling the physical reality,
- the need for consistency in handling of similar end-of-waste outputs from other product stages (B and C), with reference to the requirement that "allocation procedures shall be uniformly applied to similar inputs and outputs of the system under consideration" (Clause 4.3.4.2 of the core standard ISO 14044:2006),
- or most simply referring to the initial requirement in the same clause: "The study shall identify the processes shared with other product systems and deal with them according to the stepwise

procedure presented below" (often referred to as the ISO 14044 allocation hierarchy) requiring that whenever possible, allocation should be avoided.

The following story lines illustrate how allocation may lead to significantly different results than substitution:

- *Component reuse or recycling when the product market is saturated:* A saturated market implies that the demand can be fully met by secondary products so that no primary production is needed and some of the secondary product is treated as final waste instead of being used. When recycling capacity is limited, primary production may co-exist with secondary products being treated as final waste. Consequential modelling will model the excess output as requiring waste treatment and will assign all recycling efforts to the users of the recycled product, while crediting the users for the avoided waste treatment. This provides an incentive for additional recycling whenever recycling impacts are small and avoided waste treatment are large. Allocation will typically assign a part of the impact of the primary life cycle to the user of the recycled material, thus reducing the incentive for recycling.
- *Component reuse or recycling when demand for the product exceeds secondary supply:* Since the demand already exceeds supply, additional demand will not be able to increase recycling, and consequential modelling will therefore not give credit to users of the recycled material or component. Both the recycling effort and the avoided primary production will be included in the product system that by its supply stimulates additional reuse or recycling. This provides an incentive for additional recycling whenever impact of primary production is high and recycling impact is small. Allocation will typically give part of the recycling benefit to users, thus stimulating an already excess demand and lowering the incentive to supply the necessary component or material for recycling, e.g., through design for disassembly.
- *Co-generation of heat and power:* Consequential modelling includes the co-generation plant fully in the heat product system while subtracting the substituted marginal electricity, reflecting that heat is only produced (as opposed to vented) when there is a demand. Co-generated electricity from a plant in backpressure mode will never be included in a marginal electricity mix, although the same plant in condensation mode could be included. Allocation by exergy or revenue will assign a fixed share of the upstream impacts to the electricity, thus overestimating the impact of using heat from low-impact fuels and underestimating the impact of heat from high-impact fuels. Furthermore, revenue allocation may be heavily influenced by price regulations.

Verifiable scenarios

The ambiguous description of scenarios in EN15804:2012+A2:2019 lead to differences in interpretation and large variations in the data used for different LCAs and EPDs.

EN15804:2012+A2:2019 defines a scenario as a "collection of assumptions and information concerning an expected sequence of possible future events" but also states that "an EPD communicates verifiable, accurate, non-misleading environmental information" and requires that, e.g., the information on the Reference Service Life (RSL), which is based on scenarios, shall be verifiable. Some practitioners interpret this as a requirement that only information on average current technologies be included, since the future cannot be verified, while other practitioners note that the definition of scenarios include the term future, and see the verification requirement to be on the information used to develop the scenarios, e.g. forecasting algorithms or political plans. These differences in interpretation contributes to the large variation in data used.

2.2 Carbon accounting

The EN15804 requires the use of the GWP metric with a 100-year time horizon and prohibits accounting for the effect of temporary carbon, permanent biogenic carbon storage, and delayed emissions. The results of such calculations give an incomplete picture of the actual impacts on the global climate.

Clause 5.4.3 of EN15804:2012+A2:2019 clearly states that “The effect of temporary carbon storage and delayed emissions, i.e. the discounting of emissions and removals, shall not be included in the calculation of the GWP. The effect of permanent biogenic carbon storage shall also not be included in the calculation of the GWP.” This implies that no benefit is calculated for the temporal postponement of land use change (also known as indirect land use change), and no benefit is calculated for the temporal postponement of emissions when carbon-containing materials are kept in the building stock or recycled as a material after use, so that they remain unreleased longer than they would have if they had been left in nature.

Calculating CO_2 emitted in year 100 with the same impact factors as CO_2 emitted in year 0, fails to consider that an emission now creates more damage than the same emission later, because impacts on human health are expected to be mitigated through adaptation (Smith et al. 2014) and impacts on nature mainly depend on the speed of change, which is currently very high and decreases with the expected stabilisation and eventual decline of overall emissions (Collins et al. 2013).

The EN15804:2012+A2:2019 requires the use of the GWP metric with a 100-year time horizon. It is relevant to be aware that this metric gives 4-5 times less weight to CH_4 emissions than if using direct radiative forcing that better reflect the speed of change and thus the main impacts on nature. The tendency in the LCA community is to work with separate metrics for the rate of change and the longer-term temperature effects mainly relevant for human health, as recommended by UNEP (Levasseur et al. 2016): “To represent the complexity of climate change impacts, more than one impact category is needed. Therefore, in LCA application, we recommend considering two separate impact categories for climate change (shorter-term related to the rate of temperature change, and long-term related to the long-term temperature rise).”

2.3 Application in EPD programmes and building assessments

Defining the functional unit

Data in different LCAs and EPDs of the same products often relate to different functional units, in spite of the attempts of Product Category Rules (PCRs) to harmonise this. At the level of the building, gross area, net area, and heated area are all in use in different contexts.

When the LCA standards are applied in EPD programmes or for building assessments, one of the first challenges is to define the functional unit that all data are related to, which is essential to ensure comparability between different LCAs.

It is relevant to distinguish between different decisions that influence the final impact of the building life cycle. An initial decision is the zoning regulation that restricts what may be built where, and which can have decisive influence on important parts of the overall impact, including the extent of necessary foundations, length of supply lines (water/sewage, energy, building access), and transport needs of the building users. This may imply that some sites will already from the start have better options for achieving low life cycle impacts than others. The foundation may also be seen as an independent choice, with its own – often longer – lifetime than what is built above foundation level.

At the level of the building, different functional units are in use, notably gross area, net area, and heated area, where the former appears less related to function of the building, but some arguments can be put forward for either of the two latter. In the end, what matters is what is regarded by the customers as comparable (see Weidema 2017b), which should allow to decide between the different options. However, none of the three mentioned functional units allows consideration on the efficiency of the use of the building area, which could be an important design goal for reducing impact. The difficulty would be to find a reasonable quantifiable expression of "effective building space", which currently is a topic for further research.

Once the functional requirements to the building have been decided, the next challenge is to describe the possible combination of components to achieve these functional requirements. Here, it has often been seen as difficult to apply the concept of a functional unit in isolation from context of the full building life cycle. The task becomes a little easier when specific material choices have been made. The main role of PCRs is to harmonise the functional units for different LCAs within the same product category.

Lifetime of buildings and building components

Different PCRs have different requirements on how to make products with different lifetimes comparable. Often, a simplified normalisation of the product amount is applied, proportional to the differences in lifetime. However, such a simplified modelling will not reflect the interaction of components with different lifetimes within a building design, nor the changing reality of production technologies over the rather long lifetimes of buildings.

The lifetime is an important part of the functional unit. When comparing alternatives with different life times, it is necessary to apply a scenario that represents the consequences of the difference:

- For products with a shorter lifetime than the one defined in the functional unit, the part of the lifetime of the functional unit not covered by the product needs to be covered by a second product with the same function.
- For products with a longer lifetime than the one defined in the functional unit, the scenario can model the excess lifetime of the product either as an unnecessary waste of functionality, or as a secondary product that can displace part of a primary product.

If the second product or the displaced primary product can reasonably be expected to have identical environmental impacts as the first installed product, then the scenario can simply be prescribing a normalisation of the product amount proportional to the difference in lifetime of the first installed product and the lifetime of the functional unit, corresponding to an addition or a displacement of a proportional amount of the first installed product. However, such a simplified modelling will often not reflect the changing reality of production technologies over the rather long lifetimes of buildings and will certainly not reflect the differences in timing of emissions, cf. Section 2.2.

Another complication is that the building design itself can influence the lifetime of the different components, as e.g., when larger eaves on a house give more weather protection to windows and thus extend their predicted lifetime. Such interactions need to be modelled specifically by the building designer.

The existence of different PCRs with different requirements on how to handle the above issues is an additional complication for building designers seeking to ensure comparability between different design options.

3 Assessing impacts and improvement options of building components

There is a general agreement among the stakeholders that impact assessment and criteria setting must be done from a whole-building perspective. Although criteria for components and materials may lead to significant reductions in climate impacts, especially when addressing the components with a large and highly variable share of the total impacts (decks, foundations, load-bearing components, roofs, and windows), such criteria may also result in sub-optimisations relative to the more radical design changes that can be obtained at the building level. This is expressed very elegantly by Bionova (2018): "Improving just carbon intensity of materials, while essential, is not sufficient. The necessary improvements also require rethinking materials efficiency and materials use in building design" and "specification of recycled or renewable materials does not necessarily result into carbon reductions, and can sometimes increase the emissions. Prescriptive measures limit solutions and don't consider life-cycle, and thus bias the approaches and limit efficiency."

In spite of the above agreement among the stakeholders and the reservations in Section 2.3 on the difficulties of defining functional units in isolation from context of the full building life cycle, it should be noted that for building components within the same material type, there are large variations in the greenhouse gas emissions from production of products with identical functionality, e.g. obtained through light-weighting, as in hollow-core concrete and hollow-core bricks. Likewise, for specific material types with well-known market situations, it is uncontroversial to make requirements for actions that aim at increasing recycling or service life extension.

There is general agreement among the stakeholders that assessment needs to be performed at the early stages of the design process where the options for changing the design in an environmentally beneficial direction are largest. One way to meaningfully combine a criterion for early assessment with a verifiable outcome is the phased approach developed in the context of the Norwegian FutureBuilt programme. Here, a total of four calculations are required:

- A baseline calculation, following detailed, unambiguous rules, where the only user entry is geographical location, building type, gross area, built area, gross basement area (heated and non-heated), and number of users; all other entries are model generated from a basic rectangular box-shaped building with material use based on a knowledgebase of typical material use per building-type, energy efficiency and supply in the use stage as permitted in the current building code, and average transport patterns from the travel statistics.

- For the targeted building, where a reduction criterion relative to the baseline building must be met (in FutureBuilt the target is minimum 50% greenhouse gas emission reduction)
- For the completed building, as built, where one additional criterion can be that a minimum of components shall be based on specific data, e.g. from EPDs.
- For the building after 2 years of operation, with data for realised consumption and transport patterns of users.

It should be noted that a baseline calculation can also be made for an existing building, so that the phased approach does not exclude the possibility of an ecolabel being awarded to an existing building. Some criticism has been raised on the use of the simple box-shape for the baseline building as this makes it very hard to incorporate more complex and differentiated human-scale architectural elements without surpassing the set targets, cf. the discussion on the functional unit above. This has led to the addition of a second adapted baseline, including the same geometry and material choice as in the targeted building (Selvig 2019).

Often, the focus of building assessments is on new buildings, in spite of the large potential for reduction of greenhouse gas emissions through renovation, including lifetime extension, of existing buildings. Also here, the Norwegian FutureBuilt is one of the pioneers in criteria development with their "circular building criteria" (Nordby 2020) that contain five types of criteria:

- Documented lower life cycle emissions of the choice of demolition of any pre-existing building and building new versus renovation of the pre-existing building;
- Maximum volume and weight of construction waste per building area, and maximum percentages for landfilled construction and demolition waste out of total waste (although not specified by material types);
- Minimum percentage of reused components (although not specifying additionality);
- Design for disassembly and minimum percentage of reusable components (although not specifying potential additionality);
- Adaptability, such as independent room access, sufficient daylight, flexibility of room divisions, flexibility for additional floors, and flexibility for multiple uses and ventilation options.

4 Quality of data and databases

In this chapter, we describe the many data quality and consistency issues between databases. It is generally viewed as preferable if all data, both for the individual building LCAs and for the component EPDs, could come from one single open database, containing data relevant for each (national) market. Data with low quality also implies data with high uncertainty, limiting what conclusions can be drawn from a study, especially in a comparative context. In practice, uncertainty on unit process data is often not available and most dedicated building LCA tools do not have the functionality to propagate uncertainty to the results.

In Chapter 2, data quality was already touched upon in relation to the insufficient data quality requirements in standards and the ambiguities in the interpretation of the standards; to summarise:

- The missing completeness of data due to ignoring upstream inputs (ignoring the completeness requirement of the standards),
- The missing mass and monetary balances in unit process datasets (missing reporting requirement),

- Future scenarios using average of current technologies (ambiguity in EN 15804),
- The use of different functional units (ambiguity in standards),
- Normalisation of data to an arbitrarily chosen lifetime without adjustments for changes occurring over the actual lifetime of the building (ambiguity in standards),

as well as the ambiguities of the standards leading to data based on attributional modelling with:

- Inclusion of data for activities that cannot change their output,
- Exclusion of parts of product systems that produce more than one product,
- Inconsistent implementation of closed-loop recycling,
- Mixing of different properties for defining the system boundary (in EN 15804 requirement).

While a single database will typically be relatively consistent in the treatment of the above issues, the variation in modelling choices between databases will exacerbate the consistency problems when combining data from different databases or comparing results obtained from different databases.

Besides these issues, data quality is affected by:

- Temporal representativeness, i.e. how specific are the data to the actual time of production and consumption. Many data sources in current use are up to – and sometimes exceeding – 10 years of age, which is a problem when comparable activities develop with different speeds. Nowcasting and forecasting based on transparent and validated procedures are unfortunately not common practice.
- Geographical representativeness, i.e. how specific are the data to the actual locations of production and consumption. For example, until recently, no local Danish material data were available in the Danish building LCA tool, LCAByg. Greenhouse gas emissions for the same products often vary widely depending on local emissions regulation and local electricity generation technologies.
- Technological representativeness, i.e. how specific are the data to the actual product and the technology with which it is produced or consumed.

Clause 6.3.8.3 of EN15804:2012+A2:2019 requires that these three aspects of data quality shall be covered by a data quality assessment according to either of two specified 5-level scoring systems.

For global warming impacts, it is of course also important to ensure that LCA datasets include emissions of all relevant greenhouse gases, not only carbon-containing but also N_2O, although this is not specifically mentioned in the standards.

According to Panu Pasanen (personal communication) from Bionova, their building LCA tool 'One Click LCA' has around 100000 datapoints, which are filtered with data quality rules using metadata added by Bionova, so that users, rather than seeing an alphabetical list, see the highest quality data listed first, depending on their specific context and the data quality requirements of the certification they wish to obtain. Some data are completely blacklisted and not shown, others come with a warning, and data can also be limited to specific customers and applications.

A new Swedish/Finnish building LCA database is planned to appear in 2021, produced in a cooperation between Boverket in Sweden and the Ministry of the Environment in Finland. The datasets will cover module A1-A3 (manufacture of the construction products) and will also have data quality information, socalled Q-metadata. The intention is to make the use of such a database mandatory for building LCAs for the coming building code requirements for greenhouse gas emissions. This will require some procedural guidelines on how to handle complaints on data quality.

Due to the above-outlined consistency issues between databases, it is generally viewed as preferable if all data, both for the individual building LCAs and for the component EPDs, could come from one single database, containing data relevant for each (national) market. If the use of such a database should be made mandatory, it would require that it is made open. However, there is currently no initiatives to develop such a common database, beyond the mentioned Swedish/Finnish initiative, and the more general attempt of the EU commission to develop a database in the context of the Product Environmental Footprint scheme.

Data with low quality also implies data with high uncertainty. High uncertainty implies limitations on what conclusions can be drawn from a study, especially in a comparative context. However, in a labelling context, where the mean value provides a sharp threshold for either assigning the label or not, uncertainty on the results are not necessarily directly relevant, unless a limit value for the uncertainty is also required. Uncertainty is in any case relevant in the development of the database(s) that are used for the calculations, mainly as a tool to choose the best data sources, i.e. the data sources with the lowest uncertainty, and to direct data collection efforts towards reducing uncertainty.

It has been argued that background databases should be conservative (i.e. reflect the worst case impacts from each unit process), so as to stimulate the use of more specific foreground data. On the other hand, if instead the background database reflected the best case, it could be used to identify options for improvements. So in different contexts, both the high end (worst case) and the low end (best case) of the range of impacts provides relevant information. The ideal is to provide uncertainty on unit process data and to propagate these to the LCA results, so that both the mean value (best estimate), the high end (worst case) and the low end (best case) are visible to users. In practice, uncertainty on unit process data is often not available and most dedicated building LCA tools do not have the functionality to propagate uncertainty to the results.

5 Verification and comparability

The ISO 14025 requirements on verification and comparability do not in themselves guarantee that individual verified EPDs are comparable.

According to Clause 8.1 in ISO 14025:2010, both EPDs and the LCA data used for EDPs shall be verified by either an internal or an external (third-party) independent verifier. Third-party verification is required for business-to-consumer information, while internal verification suffices for business-to-business communication. However, the verification is not in itself a guarantee that the EPDs are comparable. Separate requirements for comparability are found in Clause 5.6 of ISO 14025:2010, but these are not required to be fulfilled for individual EPDs.

6 Availability of tools

While it is possible to perform building LCAs in generic LCA software like SimaPro, GaBi and OpenLCA, many practitioners will prefer an LCA software dedicated to building LCAs. One very versatile tool is the Finnish

'One Click LCA' software that allows import of Building Information Models (BIMs) from ArchiCAD, IFC2x3, IFC4, Revit, and Tekla. Import from Excel is also possible, and there is a functionality to create a conceptual design in a few minutes. The software supports a large number of certification programmes and national programmes and it would also be possible to adapt data to a consequential linking algorithm as the one used in ecoinvent 3, if this was a requirement from a certification organisation. The software has integrated plausibility checks for both model and data. According to Panu Pasanen (personal communication) from Bionova, the customer satisfaction is 4.5 points out of 5.

In the Danish context, the free tool LCAbyg is available for building LCAs and calculations for the voluntary sustainability class of the Danish building code. The software has some plausibility checks, such as issuing a warning if the life time of a chosen component does not match the reference lifetime of the building, but it would be desirable to add more digital plausibility checks.

According to Bionova (2018), "voluntary green building certification systems can be expected to become more demanding in terms of transparency, methodologies, and compliance of the embodied carbon and LCA methods applied. This move is motivated by the need to have a robust basis to rate projects based on carbon performance. Some systems have started verifying and approving LCA tools, allowing for innovation and competition, while ensuring verified quality for users. Eventually this capability will be integrated to other design tools used for code compliance such as energy performance tools and building design tools, such as architectural or structural software packages, eventually moving to computerized design optimization. Leading software solutions enable this already today."

A recent review on BIM/LCA integration (Obrecht et al. 2020) point out that integration is still hampered by lack of sufficiently unambiguous industry standards for both BIM and LCA as well as the diversity of national practices and terminology hierarchies in use among engineers and architects. To use the LCA information throughout the design process, from the early stages until the final documentation, integration into the BIM tools of LCA information and functionality, including use stage energy demands, appear a more relevant option than the reverse. Cavalliere et al. (2019) present an example of such integration that would be compatible with the approach of the Norwegian FutureBuilt programme described in Chapter 3.

7 The legislative environment

In the current European regulation context, the only construction products certification that can be required is the CE marking, which is regulated in the EU Construction Products Regulation (CPR) 305/2011/EU. All Nordic countries are at different stages in considering introducing limit values for the life cycle global warming impact of building, which will require LCA calculations, and thus that generic building LCA databases be available at least at the national levels.

In Denmark, a voluntary sustainability class has been introduced in the building code. In Finland, legislative requirements are expected by 2025.

Bionova (2018) provides a global overview of current regulations and rating systems for embodied carbon in construction works.

In addition to these building specific regulations, the potential introduction of a carbon tax can affect the building sector. However, until the actual implementation measures have been decided, it is difficult to say what synergies this may have with ecolabelling requirements.

8 Feasibility and potential impact of adding additional ecolabel criteria

8.1 Consistency and comparability of results from calculation tools

We note that the ISO 14044 and EN 15804 standards are often applied with an attributional interpretation, leading to modelling results that do not follow the physical reality and leads to perverse incentives, as described in Chapter 2. In practice, the attributional approach is seldom followed strictly. Most attributional LCAs combine elements of attributional and consequential modelling, and the detailed allocation requirements of EN 15804:2012+A2:2019 are seldom – maybe never – followed strictly. We are not aware of any systematic assessment of the extent and importance of the resulting inconsistencies in the attributional datasets applied for building EPDs and LCAs.

By requiring loads and benefits of secondary material, secondary fuel or recovered energy to be reported in a separate module D instead of integrating these unit processes with the life cycle stages they belong to, the mandatory modularity has become a complication rather than the "easy organisation and expression of data packages" (Clause 6.3.5.1 of EN 15804:2012+A2:2019) that was intended. In practice this makes the reporting of substitution more cumbersome and biases the practitioner towards applying allocation instead.

Comparing the requirements for comparability of EPDs in Clause 5.6 of ISO 14025:2010 with the actual variability in the quality of data used for building LCAs, as summarised in Chapter 4, we do not feel confident that current building LCA calculation tools and their database implementations of different standards and methods provide results that are sufficiently consistent and comparable to be the basis for calculations for the Nordic Ecolabelling programme.

The above data quality issues are exacerbated by the lack of accounting for the temporality of greenhouse gas emissions, as described in Section 2.2.

8.2 Meaningful incentives from ecolabelling criteria

In spite of the limited consistency and comparability of building LCA results described in Section 8.1, there are a number of areas where sufficiently robust conclusions can be drawn from current knowledge and that can be used as basis for developing ecolabelling criteria for building materials with a verifiable high reduction effect on global warming:

- While there is insufficient evidence to recommend one material over another, once a specific material has been chosen, there are large variations in the greenhouse gas emissions from production of products with identical functionality, e.g. obtained through light-weighting, as in hollow-core concrete and hollow-core bricks. Care should be taken to ensure that greenhouse gas emissions are not reduced by accounting for input of recycled materials, except when these come from saturated markets.

- Reduction in waste at the building site, e.g., through the use of factory pre-dimensioned building components, allowing more efficient use of material and easier reuse of waste.
- Actions that aim at increasing recycling, such as design for disassembly, minimum recycling targets for renovations specified by material type according to the actual market situations, and recycling credits for use of recycled materials from saturated markets.
- Optimised building shape to reduce material demand.
- Adaptable design, such as independent room access, sufficient daylight, flexibility of room divisions, flexibility for additional floors, and flexibility for multiple uses and ventilation options, to the extent that this does not significantly increase material demand.
- Service life extension, through requirements on guaranteed durability or through design, such as larger overhangs to protect windows, to the extent that this reduces net material demand over the (extended) service life.

Some examples of the size of greenhouse gas emission reduction from such design and construction strategies can be found in Malmqvist et al. (2018).

In addition to the above areas where meaningful specific ecolabelling criteria can currently be developed, it would be meaningful to signal that climate impact calculations are expected to become relevant in the future, when the current consistency and comparability problems have been overcome. To this end, a point criterion could be added for a third party reviewed climate impact calculation in which at least three (or more) of the following requirements have been met:

- The completeness of the calculation is checked by a mass and monetary balance for the product system, and the percentage deviation from completeness is reported,
- Consequential linking is applied to unit processes representing at least (x)% of the mass and monetary inputs and outputs of the product system,
- Mass and monetary balances are applied to ensure completeness of unit processes representing at least (x)% of the mass and monetary inputs and outputs of the product system,
- Future scenarios are applied that are based on realistic and transparent procedures,
- All unit processes are clearly specified in time,
- Uncertainty is provided on intermediate flows representing at least (x)% of the life cycle cost of the product, and on input and output flows representing at least (x)% of the total mass of inputs and outputs of the product system.

All of these requirements can be seen as supported by the current standards.

Due to the disparity in the speed of the legislative development among the Nordic countries, it does not appear as an option to link the ecolabelling requirements to the legislative requirements at the current time.

9 Recommendations for the criteria development of Nordic Ecolabelling

Our recommendations are divided in two parts, one for the short-term and one for the longer term:

9.1 Recommendations for the short-term

Due to our reservations with respect to the consistency and comparability of results from current building LCA calculation tools (see Section 8.1), our recommendations in the short term are limited to those issues that do not require such consistency and comparability for ecolabelling criteria to be verifiable. This implies that we recommend any additional ecolabelling criteria for building materials for now to be limited to the issues listed in Section 8.2:

- Requirements on specific construction products with identical functionality, where greenhouse gas emission reductions are clearly verifiable, e.g. when obtained through light-weighting.
- Requirements aiming at increasing recycling, such as design for disassembly and minimum recycling targets specified by material type.
- Requirements to reduce overall material demand over the forecasted service life of the building under well-specified, realistic use scenarios.
- Requirements on a third party reviewed climate impact calculation for the product in which at least three (or more) of the requirements listed in Section 8.2 have been met.

9.2 Recommendations for the longer term

It is obviously not the role of the ecolabelling programmes to rectify the current consistency and comparability problems outlined in Chapter 2. Nevertheless, in order to incentivise radical building design changes, it is imperative to reach a situation where ecolabelling criteria can be set from a whole building perspective, based on LCA calculations. Obtaining consistent and comparable results from LCA calculations is an issue that is not limited to building materials. We recommend to seek cooperation with other stakeholders with similar interests, with the aim of establishing a common open database that:

- Uses as basis an open hybrid IO-LCA database with global coverage, e.g., Exiobase 3 hybrid,
- Requires consequential linking of unit processes,
- Enforces a strict completeness requirement on unit processes, using mass and monetary balancing,
- Includes future scenarios based on realistic and transparent procedures,
- Requires activities, and thus flows, to be clearly specified in time, and
- Requires all flows to be provided with uncertainty.

All of these aims can be seen as supported by the current standards. However, this should not prevent Nordic Ecolabelling from seeking, at the next revision of the standards, the removal of their current ambiguities, described in Chapter 2.

An issue that cannot be tackled within the limitations of the current EN 15804 is to apply an impact calculation for global warming that better reflect the temporal dependency of this impact category, as described in Section 2.2. However, once the information on the timing of emissions is included in the data, Nordic Ecolabelling can still require a separate impact calculation, outside the limitations of current standards.

Once a database with the above specifications has been established, we recommend that Nordic Ecolabelling requires LCA calculations to be performed with data from this database, unless the user can provide improved data. We recommend that such calculations be required at the whole building level, in a phased approach comparable to that currently applied in the Norwegian FutureBuilt programme, as described in Chapter 3. Our recommendation is for the principle of a phased approach, not for the specific data or targets required by the FutureBuilt programme. Rather than targets for greenhouse gas emissions, we recommend that targets be set for global warming impacts using the adjustments for the timing of emissions described in Section 2.2.

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