Critical Issues When Comparing Whole Building & Building Product Environmental Performance

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Executive summary

Introduction

Guides, standards, product category rules, and environmental product declarations have emerged to evaluate environmental impacts within the buildings sector. These efforts have certainly moved the field forward, but as of yet still do not ensure comparability among building products or whole buildings. In this paper, we aim to address critical issues and make recommendations to practitioners and those developing guidance to enable more robust comparisons of building products and whole buildings.

Recommended current practice and future advances

We classify critical issues when comparing building and building product environmental performance into two categories: system boundaries and analytical approach. As we discuss each of the critical issues in this report, we recognize that there is a desire to perform these comparisons today that cannot be put off until methodologies advance further. We therefore offer two kinds of recommendation: current practice and *future advances (noted in italics)*. For *future advances* we offer suggestions for research that would enable the recommendations to be implemented.

System boundaries category

- **Boundaries and inclusion of life cycle processes**
    - Comparative assessments of the environmental impact of buildings and associated building products must have consistent system boundaries.
    - Always include operational energy consumption (module B6 from the standard EN15804) in whole building LCA.
    - Several quantities should be calculated and reported separately:
        - EN 15804 modules B1 (use of installed product), B3 (repair), B5 (refurbishment), and B7 (operational water use).
        - Preparation and maintenance of lot.
        - Relevant downstream and beyond building life processes for building products.
    - *Future: The research community should advance methods for estimating the use phase modules B1, B3, B5, and B7.*
    - *Future: Expected damage due to hazards should be explicitly included in future whole building LCA standards.*
- **Reference study period**
    - Need to use the same reference study periods (RSP) for comparison.
    - Report the life cycle impact of buildings and building products assessed at several RSPs.
    - End of life processes that cause emissions beyond the RSP should be included.
    - *Future: Research is needed to support justification of building and building product lifespans.*
    - *Future: Research should inform the time period for long-term end-of-life emissions.*

Analytical approach category

- **Type of LCA model**
    - Currently, attributional LCA is the practical choice for LCA models.
    - *Future: Consequential LCA can be used to support building-related policy decisions.*

- **Criteria for functional equivalence**
  - Only compare building products in the context of a whole building.
  - Comparisons among building products and whole buildings should only be done when there is consistency in function, scenarios, and life cycle inventory datasets.
  - Comparisons of normalized impacts should be avoided unless functional equivalence has been defined.
- **Geography**
  - Comparisons of buildings and building products must be conducted using the same location.
  - Building products with different supply chain geographies can be compared.
- **Treatment of time**
  - Current best practices capture the impacts of the activities that fall within the RSP.
  - *Future: The use of dynamic LCA can help inform more accurate assessments, though it will require a considerable transition in the methods of calculation.*
  - *Future: Assessments could incorporate scenarios for the evolution of emissions from energy sources.*
- **Uncertainty analyses**
  - Perform and report uncertainty analysis.
  - Assessments should capture underlying data uncertainty.
  - Report results at each life cycle module for several scenarios.
  - *Future: Guidance could define characteristics for a set of scenarios.*
- **Allocation**
  - If possible, use of subdivision resolves the multi-functionality problem.
  - If subdivision is not possible, the outcomes of assessments should be reported for multiple allocation approaches.
  - *Future: PCRs should dictate the appropriate approaches to address multi-functionality.*
  - *Future: Assessments with consequential LCA could also incorporate the system expansion approach.*
- **Treatment of operational energy**
  - Operational energy use must be modeled for each building design.
  - All building operations parameters should be equivalent unless they are a component of the analysis.
  - Input a common set of reference values as assumptions where appropriate.
- **Treatment of biogenic carbon**
  - Complex models of reality are the appropriate benchmark for conclusions about biogenic carbon.
  - Assumption of biogenic carbon neutrality is too simplistic. Some situations may be a net carbon sink or a net carbon source.
  - The set of forest carbon assumptions should be equivalent for comparison. These include:
    - Reference situation for land use change
      - The reference land-use situation should be defined as ‘no use’ in attributional LCA.
    - Timing of emissions and sinks and time horizon

            - Currently, the practical approach is to consider whether an activity occurred within the RSP.
            - *Future: Moving to the use of dynamic LCA will enable proper assessment of the timing of emissions and sinks.*
        - Carbon storage in products
            - Carbon storage time period and effects should be reported separately.
            - *Future: Methods for estimating carbon storage should consider that only part of the harvested tree is stored in products.*
        - Scope of forest carbon stock
            - Forest carbon stock models should be inclusive of all terrestrial carbon stocks.
        - Approach to forest carbon stock estimates
            - Estimates should be based on a dynamic forest carbon stock model.
        - End-of-life
            - The fate of a product at and beyond its end-of-life can have a considerable impact on its life cycle carbon balance.
- **Treatment of end-of-life**
    - Scenarios for end-of-life need to be reported for buildings and building products.

Contents

Introduction

Given the complexity of buildings and buildings products, care must be taken to conduct thorough assessments of their environmental impacts. This is especially true when comparing one building design or building product to another for the purpose of informing decisions.

Guides, standards, product category rules, and environmental product declarations have emerged to evaluate environmental impacts within the buildings sector. They use life cycle assessment (LCA) to quantify environmental impacts. These efforts have certainly moved the field forward, but as of yet still do not ensure comparability. In this paper, we aim to address critical issues and make recommendations to practitioners and those developing guidance to enable more robust comparisons. The objectives of this paper therefore are to:

- identify the critical issues present when quantifying the environmental impacts of whole buildings as well as the building products that comprise them,
- emphasize the elements that must be considered when evaluating claims made between two types of buildings or building products,
- review, critique, and recommend current best practices related to the critical issues,
- offer suggestions of research topics that would advance the state-of-the-art and could possibly be used in future standard and PCR development.

Identification of critical issues

As mentioned, there exist sets of relevant standards and guides for assessing and comparing the environmental impact of buildings, building products, and products in general. Chief among them are a set from the International Organization for Standardization (ISO) and another from the European Committee for Standardization (CEN). Product category rules (PCRs) are derived from these standards, which offer detailed guidance for environmental product declarations (EPDs) for building products and whole buildings (EPDs for whole buildings are sometimes referred to as environmental building declarations, or EBDs). Please see the Appendix for a detailed overview of these and related documents.

Organizations have also published relevant guides to aid practitioners. Athena Sustainable Materials Institute has published a guide for use in green building programs (Bowick, O'Connor, & Meil). Certification and rating programs like LEED, HERS, and EnergyStar also assess buildings and building products, but not strictly from an LCA framework. The American Institute of Architects produced a thorough guide which preceded the introduction of most building-specific standards (Bayer, Gamble, Gentry, & Joshi).

EBDs and EPDs are reports of analyses of very specific buildings and products. Often researchers are interested in quantitative comparisons of types of buildings and types of products more generally in order to draw conclusions and provide recommendations to the building design community and policymakers. Therefore, we address the conditions that should be met to enable comparability.

We classify the critical issues into two overarching categories shown in Table 1: system boundaries and analytical approach. In order for these assessments to take place now, we advocate the use of current best practices, which in the coming years will evolve as consensus forms around methodological advances. We look to the existing standards and PCRs as well as the literature to inform our assessment. For whole building assessment, we particularly review the first and only buildings PCR (to our knowledge), developed in 2014 by the International EPD system (International EPD® System, 2014) which is based on a variety of ISO and CEN standards.

Table 1: Set of critical issues identified and discussed in this paper

Category	Critical issue
System boundaries	Boundaries and inclusion of life cycle processes
	Reference study period
Analytical approach	Type of LCA model
	Criteria for functional equivalence
	Geography
	Treatment of time
	Uncertainty analyses
	Allocation
	Treatment of operational energy
	Treatment of biogenic carbon
	Treatment of end-of-life

Recommended current practice and future advances

As we address each of the critical issues identified, we recognize that there is a pressing need to perform these comparisons today that cannot be put off until methodologies advance further. We therefore offer two kinds of recommendations: current practice and future advances.

Recommended current practices take into account what is feasible given the tools and datasets available to practitioners today, while emphasizing consistent and comprehensive assessments.

Recommend future advances (noted in italics) consider promising approaches being developed in the literature, and point to gaps that should be filled to enhance the precision and accuracy of assessments.

System boundaries category

Boundaries and inclusion of life cycle processes

Comparative assessments of the environmental impact of buildings and associated building products must have consistent system boundaries. The standards have categorized the processes that occur during and beyond a building's life cycle into modules: A1-A3 are product stage, A4-A5 are construction stage, B1-B7 are use stage, C1-C4 are end of life (EOL) stage. Module D is not a life-cycle stage, per se, but rather a module to capture environmental impacts beyond the system boundary. In addition, there are other decisions around system boundaries such as cut-off rules for upstream burdens, capital goods, and products within the building (e.g., appliances, fixtures, flooring, etc.).

Always include operational energy consumption (module B6) in whole building LCA, and only compare building products in the context of a whole building. Although operational energy consumption (module B6, energy use to operate building integrated technical systems) is known to dominate the environmental impact of existing buildings over their life cycle, some guides, standards, and rating programs treat its inclusion as optional. Some programs allow for building designs to be compared based on the sum of other modules —those specific to building products—as long as the operational energy meets certain criteria (Bowick et al.).

We agree with Section 5.3 of (European Committee for Standardization) which states that "comparison of the environmental performance of construction products using the EPD information shall be based on the product's use and its impacts on the building, and shall consider the complete life cycle (all information modules)" and further notes that "EPD that are not in a building context are not tools to compare construction products and construction services". This topic is further discussed in the analytical approach category in this paper.

Several quantities should be calculated and reported separately:

- EN 15804 modules B1 (use of installed product), B3 (repair), B5 (refurbishment), and B7 (operational water use).
- Preparation and maintenance of lot.
- Relevant downstream and beyond building life processes for building products.

EN 15804 modules B1, B3, B5, and B7. Athena SMI (Bowick et al.) notes that modules B1 (installed products in use), B3 (repair), B5 (refurbishment), and C3 (waste processing) "are not currently well supported by North American LCA databases and tools". We note that B1, B3, B5, and B7 (operational water use) are absent from Athena Impact Estimator reports but C3 is included. While methods for estimating water usage are being developed by researchers (Cheng; House-Peters, Pratt, & Chang) and some reference consumption rates are available (Alliance for Water Efficiency; EERE), the whole building standards and PCR do not provide sufficient guidance currently. Note, however, that typical operational energy consumption calculations include assumptions about hot water consumption to estimate heating. EN 15978 calls for irrigation to be included, which clearly is associated with the location and lot rather than building exclusively (see issue below about lots).

While it may prove difficult to estimate these modules, it is important to have a sense of whether their impacts are significant, requiring refined estimation in order to arrive at reasonable life cycle estimates. The (International EPD® System) does not advocate for separate reporting. However, lacking adequate and consistent reference values, poor estimates could lead to erroneous comparisons.

Preparation and maintenance of lot. Departing from guidance in the standards and (International EPD® System), we argue that the performance of the building is largely separate from the surrounding lot. Further, since no two lots are exactly the same, inclusion will limit comparison. In module A5 (construction and installation), "ground works and landscaping" and likewise in module B7 "Irrigation of associated landscape areas" are instructed to be included by the PCR. We previously recommended that module B7 be reported separately, and extend that recommendation to include the ground works and landscaping in A5.

Relevant downstream and beyond building life processes for building products. Standards all require that upstream processes are included in assessments of building products (cradle-to-gate); the downstream processes are only included in the optional cradle-to-grave assessment. If a practitioner attempts to use a cradle-to-gate EPD as part of an assessment of a building, then the burden is on them to fill in the gaps and estimate the maintenance, replacement, and EOL fates. While the manufacturer may not know precisely what the impact associated with those modules may be, they could gather that information on plausible scenarios more easily than others, and thereby enable consistent estimation of their products' downstream processes across building assessments. Estimating impacts of materials after the building life and defining the associated scenarios will facilitate the transition of our society towards a circular economy where reuse of materials is incorporated into product design.

Module D, benefits and loads beyond the system boundary, is typically optional and excluded from the sum of the life cycle impacts. Leaving it off of an EPD places the data burden on the practitioner if they aim to estimate the sum of module D impacts across products in a building. We agree that module D does not need to be included in the total and it should be emphasized that the impacts due to these processes are outside the scope of the reference study period and building life cycle. However, consistent calculation of Module D improves our understanding of the impacts of different material reuse scenarios.

Future: The research community should advance methods for estimating the use phase modules B1, B3, B5, and B7. The dearth of data related to these modules prevents accurate calculations around their impacts on buildings' life cycle performance. We therefore suggest that B1, B3, B5, B7 currently be reported separately and not included in the life cycle sum. We advocate that the research community develop methods to easily enable their estimation for future analyses.

Future: Expected damage due to hazards should be explicitly included in future whole building LCA standards. Communities and policy makers are increasingly recognizing the value of resilient infrastructure, from an economic and environmental perspective. Natural hazards such as hurricanes, flooding, earthquakes, and wildfire can damage or destroy a building, leading to the need for repair or replacement of building products. The likelihood of the extent of the damage is based on a combination of the location's expected hazard intensity and the hazard resistance of building design features. The science and engineering models to perform these hazard damage estimates are evolving rapidly and LCAs have already been conducted incorporating expected damage due to hazards.

Gaps remain, though, in estimating the type and quantity of building products requiring repair or replacement. In order to properly account for the potential benefit of hazard resistant features in a building design under comparison, researchers should attempt to bridge these gaps. As these models are developed and validated, whole building LCA standards should respond by explicitly including use phase hazard damage in the modules.

Reference study periods

Need to use the same reference study periods (RSP) for comparison. It is essential that buildings under comparison are assessed with the same reference study period (RSP). There is no correct number to use for an RSP – it is selected based on the objectives of the study. However, it is important to understand how the number relates to the required service life (ReqSL) of the building (which is required by the client or regulations). The RSP is often dictated by the ReqSL (for example, (International EPD® System) states that the RSP should equal the ReqSL), but there may be cases where the RSP is greater than the ReqSL (in which case significant refurbishment or demolition and construction would need to be included in the analysis) or the RSP is less than the ReqSL (in which case the use phase burdens need to be decreased appropriately). If a longer RSP is chosen, then use phase processes become more important, while shorter RSPs emphasize the upstream processes. When comparing two buildings, the relative life cycle impacts will likely depend on the chosen RSP, thereby reinforcing the need to do comparisons using the same set of assumptions.

(Aktas & Bilec) found that life cycle impact results are very sensitive to building lifetime assumptions (i.e., ReqSL) and recommend not making an arbitrary assumption. They estimated the average residential lifetime at 61 years for buildings in 2009 with a 90% confidence interval of 21 to 105 years, and found average lifetimes are becoming increasingly longer. (US DOE) found a median of 50-60 years for commercial buildings in 2003 with a considerable range. These data may be used to inform the selection of ReqSL, but not necessarily RSP. This same set applies to building products for EPDs. We recommend that future iterations of standards and PCRs adapt this approach.

Report the life cycle impact of buildings and building products assessed at several reference study periods. To enable comparison across buildings while considering building lifetime variability, analyses should report life cycle impacts for a common set of RSPs. Since there is no true value for a RSP, a range should be chosen that could represent different scenarios, such as RSP equal to ReqSL, RSP greater than ReqSL, and RSP less than ReqSL.

From a practitioner's perspective, once the calculations are set up to assess the building or products at a particular RSP, it is not very difficult to extend those calculations to assess impacts at other RSPs. The extension involves summing the building product use phase processes over a different number of years for each RSP.

End-of-life processes that cause emissions beyond the RSP should be included. Section 7.4.5.5 of EN 15978:2011 states: "For some end-of-life processes such as land-filling, emissions can occur after the time period of the assessment. As a rule, a time period of 100 years is considered appropriate for such long-term processes." We interpret this to mean that emissions from long-term processes such as landfills should be accounted for 100 years after the EOL process, which is 100 years after the RSP. This is important considering that some building products decay slowly in a landfill.

Future: Research is needed to support justification of building and building product lifespans. As is the case with modules B1, B3, B5, and B7, the lack of data on building and building product lifespans prevents informed lifespan calculations. The research community should collect more lifespan data in this area.

Future: Research should inform the appropriate time period for long-term end-of-life emissions. The scientific basis for the 100-year time period is not readily apparent. In future standards, this post-end-of-life period could be based on a pertinent metric, such as the point at which the product has reached 95% of expected total decay.

Analytical approach category

Type of LCA model

Currently, attributional LCA is the practical choice for LCA models.

Attributional LCA is also referred to by names such as "book-keeping", "accounting", or "average" LCA. Its purpose is to "determine the impact of the functional unit (FU) chosen to characterize a production system" (Rehl, Lansche, & Müller). Currently, it is the model most commonly used, and we advise that it be used for building-related LCA.

Future: Consequential LCA can be used to support building-related policy decisions.

Consequential LCA is also referred to by names such as “change-oriented”, “market-based”, “marginal”, or “prospective”. “The approach is used to identify the technology affected by a change in demand” and “is applied to obtain information about the changes in pollution and resource flows caused by a change in demand or in the output of the functional unit” (Rehl et al.). In the buildings context, this approach will be useful to inform decision-makers about the consequences of shifting building designs and technologies. It is particularly relevant in the policy arena where an understanding of widespread changes is important. Examples could include the assessment of policies influencing materials used in buildings or the environmental footprint of building energy sources.

Criteria for functional equivalence

In LCA, comparison requires functional equivalence. We differentiate the criteria for functional equivalence of building features and whole buildings.

Since building products need to be compared in the context of a whole building, all other building attributes need to be equivalent. This criterion is unlikely to be met when comparing documents prepared by separate practitioners, so we recommend these comparisons take place between assessments prepared by practitioners using a consistent approach.

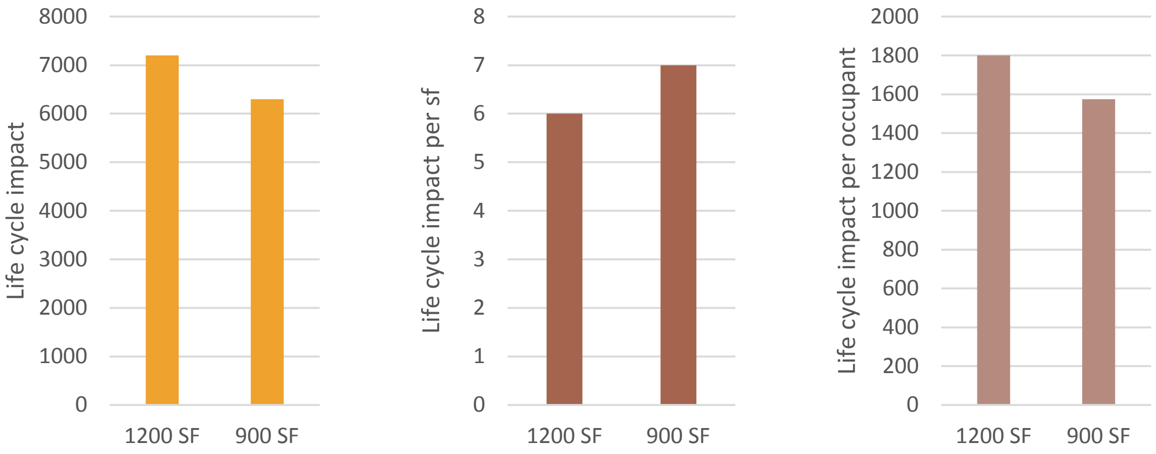
Only compare building products in the context of a whole building. With regards to building products, unless the thermal properties, such as thermal conductance and thermal diffusivity, and envelope permeability are exactly the same, use of the products under comparison would cause different operational energy consumption (as described above in System Boundaries). Therefore, we again assert that building products can only be compared in the context of a building.

In their discussion of product substitution, (Brunet-Navarro, Jochheim, & Muys) describe replacement of products “satisfying the same function”, but many studies do not fully follow this principle. (Sathre & O’Connor) found in their meta-analysis of 21 studies on wood product substitution that the “studies focus on the production phase of the products, and often include the end-of-life phase, but in general do not explicitly consider the operation phase of the products”. While most were in the context of a building, the exclusion of the use phase which often dominates the life cycle impact could lead to erroneous conclusions. (Upton, Miner, Spinney, & Heath) summarize that prior studies “demonstrate the importance of residential heating and cooling to life cycle energy requirements and CO2 emissions associated with residential structures”, but exclude it from their comparison, noting that when heating and cooling requirements are comparable, wood building systems outperform others in terms of embodied energy. We argue that heating and cooling requirements are only comparable in this regard if precisely equivalent.

Comparisons among building products and whole buildings should only be done when there is consistency in function, scenarios, and life cycle inventory datasets. Establishing functional equivalence can be difficult because functionality can be defined in many ways (shelter, safety, pleasure). It is difficult to ensure functional equivalence between building products or whole buildings assessed in separate studies. It is also unlikely that scenarios in separate analyses are consistent, or that the same background life cycle inventory datasets have been used. Therefore, it recommended that practitioners perform comparative assessments of buildings and building products in a consistent manner in order to ensure equivalence of other parameters.

To compare building products, design buildings that are otherwise the same, and substitute the building products. This may require substituting associated products as well; in this situation, the group of building products (an assembly or sub-assembly) is the smallest unit suitable for comparison. For example, exterior wall systems like insulated concrete forms (ICF) require both concrete and rigid foam, while wood stud cavity walls typically use non-rigid insulation as well as sheathing, an air infiltration barrier, and possibly termite barriers. In such a case, a specific ICF wall would need to be compared to a specific wood stud cavity wall; comparison of the concrete to the wood directly is infeasible. The function of the buildings must be the same, but the performance may not (e.g., there will likely be differences in energy consumption).

Comparisons of normalized impacts should be avoided unless functional equivalence has been defined. The (International EPD® System) states that for project comparison, the functional classification of the building (e.g., residential, office, retail) and its area must be taken into account. Therefore, the total environmental impacts are reported along with those impacts normalized by the temperature-controlled floor area to enable comparison on a per-area basis. A challenge with this approach is that when comparing two buildings with different floor area designed for the same number of people, occupants or employees, the smaller one will have a lower total impact but a higher per-area impact. For example, the illustration below compares the life cycle impact of a three-bedroom house designed to be the same except for the living area: one is 1200 SF and the other 900 SF. The normalized impact suggests the 1200 SF house is preferable, but the total impact suggests the opposite. A comparison on the basis of the former would offer incorrect design guidance. This is important as the average size of newly constructed homes in the US grows each year. This highlights the importance of avoiding such normalized comparisons of buildings with different functions.



Total life cycle impact Impact normalized per area Impact normalized per occupant

Figure 1: Comparison of normalization by different common reference units for hypothetical buildings

Geography

Comparisons of buildings and building products must be conducted using the same location. The location will impact the transportation requirements, electrical grid and associated emissions, and climate-induced heating and cooling demand. The objective of the comparison of buildings will influence the geographical constraints. If the objective is to compare the life cycle impact of a single building design in location X versus location Y, then comparing across geographies is certainly appropriate. If instead the comparison has the more common objective, aiming to compare different building designs, then the geographical location should be the same. The latter is consistent with whole building LCA comparison requirements set forth in (ASTM).

Building products with different supply chain geographies can be compared. Since the building products industry exists in a largely globalized economy, builders may have the choice of products sourced from around the world. It is appropriate to compare, for instance, a window manufactured in China with one manufactured in Germany (in the context of a whole building, as described above). Upstream processes along the supply chain are influenced by the location, particularly the manufacturing plant efficiency, the electricity grid and transportation distances and modes. These location-specific impacts should be taken into account when selecting a product based on its environmental performance.

Treatment of time

Current best practices capture the impacts of the activities that fall within the RSP. This includes long-term emissions from end-of-life activities, such as landfill emissions that continue to occur beyond the RSP (EN 15978:2011 recommends including emissions occurring up to 100 years beyond the RSP). As discussed above, impacts in module D are reported separately. When accounting for global warming potential (GWP) of greenhouse gasses, the 100-year time horizon is used.

Future: The use of dynamic LCA can help inform more accurate assessments, though it will require a considerable transition in the methods of calculation. Dynamic LCA accounts for the instantaneous and cumulative global warming impacts by assessing the radiative forcing that occurs as the result of a greenhouse gas emission at a point along the life cycle (Levasseur, Lesage, Margni, & Samson). Research is needed to better understand the implications of the timing of radiative forcing on building environmental impacts.

Authors (Levasseur, Lesage, Margni, Deschênes, & Samson) have studied the shortcomings of this approach as it pertains to carbon accounting, and instead propose dynamic LCA. They note that "[r]eleasing a big amount of pollutant instantaneously generally does not have the same impact as releasing the same amount of pollutant at a small rate over several years" and that pollutants have different lifetimes. Also, applying a GWP value with a fixed time horizon to the sum of impacts occurring over the life cycle results in inconsistencies between the time horizon and the RSP.

A noteworthy consideration is that the current approach does not assign more weight to carbon emitted now versus carbon emitted later, since the results are independent of the timing of the emissions. When using dynamic LCA, an emission made later will have less impact than one made sooner, since it will be included for fewer years in the cumulative impact. This should be dealt with carefully.

Future: Assessments could incorporate scenarios for the evolution of emissions from energy sources. Emissions associated with energy sources often are the chief drivers of environmental impacts of building products manufacturing and operational energy consumption. Electricity grid mixes are changing around the world in response to a variety of pressures like climate change and energy independence. Given that, modeling future emissions based on current emissions is somewhat inaccurate. Incorporating scenarios for future energy sources, as (Sandin, Peters, & Svanström) have demonstrated, would further enhance the robustness of comparative assessments and guide decisions.

Uncertainty analyses

Perform and report uncertainty analysis. Very little about a building along its life cycle is known precisely, especially in terms of its use and fate after construction. Most LCAs report deterministic results representing the outcome of a specific default scenario.

Assessments should capture underlying data uncertainty. Additionally, there is uncertainty in the bill of activities and associated environmental impact data used in calculations. EPDs could incorporate uncertainty in their estimates. If generic building product data is used from environmental impact databases (such as ecoinvent) when EPDs are lacking, data uncertainty can be estimated. Statistics like mean and standard deviation or confidence intervals could be reported to characterize the uncertainty.

Report results at each life cycle module for several scenarios. To better capture the range of possibilities, we propose that each assessment report a set of scenarios. These scenarios will be qualitatively different depending on the life cycle stage and type of building product. For instance, operational use scenarios could pertain to occupant lighting schedules. End-of-life and beyond scenarios vary by the product.

Future: Guidance should define characteristics for a set of scenarios. To facilitate the combination of these scenarios across multiple building products in the context of the whole building, it would be beneficial for a range of potential scenarios to be defined for use in LCAs. These scenarios could be defined per region based on statistical analysis of building or occupant performance and projections, or agreement of practitioners on likely operating performance. The scenarios could then be incorporated into standards and PCRs.

Allocation

When preparing the life cycle inventory of a material used in a building product or an energy source used to create electricity, a multi-functionality problem often arises. The problem typically relates to situations where there are more than one outflow (co-products or by-products) from a process. For example, materials obtained from mines often produce more than one type of metal. Crude oil transforms into many derivative products aside from the diesel used to transport materials. The stem of a harvested tree can create wood products while the residual can be incinerated for energy. How should the benefits or impacts of the production processes be approached?

(Wardenaar et al.) reviews the problem and the on-going debate around the set of approaches to address multi-functionality developed by the LCA community in their discussion of bio-energy policies. In their case study, they found that the choice of method has “considerable impact on the outcomes of an LCA”. They discuss the pros and cons of four main approaches:

> “*Subdivision*: disentangling a process that has been recorded as a multi-functional unit process into the constituent mono-functional unit processes
>
> *System expansion:* avoiding the multi-functionality problem by broadening the system boundaries and introducing new processes and several functional units
>
> *Physical partitioning*: the artificial splitting up of a multifunctional process into a number of independently operating mono-functional processes, based on physical properties of the flows (e.g. mass, energy, carbon content, etc.)

> *Economic partitioning*: the artificial splitting is based on economic properties of the multifunctional process, such as the gross sales value or the expected economic gain"

If possible, use of subdivision resolves the multi-functionality problem. By "disentangling" a multi-functional process into a mono-functional process, the problem is resolved. Therefore, we agree with this portion of the ISO hierarchical approach which places subdivision as the preferred approach.

If subdivision is not possible, the outcomes of assessments should be reported for multiple allocation approaches. Comparing the other approaches, we agree with the authors' argument that "there is no objectively correct way to solve the multi-functionality problem". We also agree that for the purpose of informing policy, the LCAs aim for "consistency and robustness". Simply picking an approach solves the issue of consistency for comparison, but still another approach may be equally valid. We acknowledge the data challenges inherent in the system expansion approach. Therefore, we advocate that physical and economic partitioning be assessed and reported.

Future: PCRs should dictate the appropriate approaches to address multi-functionality. Some PCRs currently specify which allocation approach should be followed, while others defer to the ISO hierarchy preferring physical over economic. Considering that there is strong alignment in the production processes within products represented by a PCR, the document should specify the appropriate approaches to multi-functionality issues. Generally, unless subdivision is possible, this would represent multiple allocation approaches.

Future: Assessments with consequential LCA could also incorporate the system expansion approach. (Rehl et al.) describes that the system expansion is used to solve the multi-functionality of a process. Along with a future transition to use of consequential LCA, the system expansion approach can be used. The research community will need to enhance methods and data to facilitate its use more broadly, though.

Treatment of operational energy use

Operational energy use must be modeled for each building design. EN 15978 allows the operational energy use in module B6 to be based on "energy modelling and scenarios for the patterns of use". The inherent challenge is that each building product has different thermal properties that affect the heating and cooling demand of the building, which can be a significant portion of the operational energy use. Different building products used in the walls, roof, or floors will almost certainly result in different operational energy use. Even relatively small differences in the expected annual operational energy use can be significant when multiplied by the years in the analysis period. Explicitly accounting for these differences by modeling energy use therefore becomes extremely important and should be used instead of approaches that make simplifying assumptions such as equivalent energy use across alternatives, or use of reference values from representative building types.

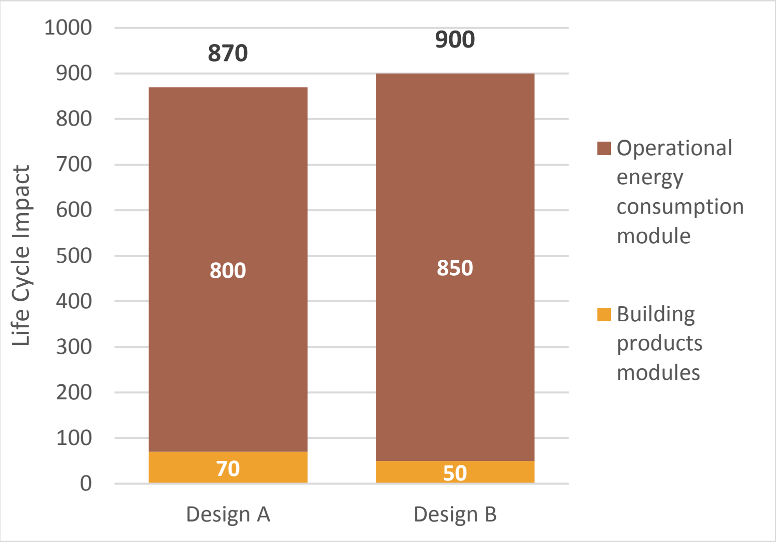


Figure 2: Comparison of operational energy use module and building products modules across two hypothetical designs

There are instances when comparing building designs, such as the one illustrated in the diagram to the left, when the life cycle impact of Design B is greater than Design A even if its building product impact is lower. This can occur if the building products used in Design A result in a considerable reduction in operational energy consumption. Such a situation is discussed by (Fouquet et al.). These tradeoffs are only observed if operational energy use and building products modules are assessed jointly.

<u>All building operations parameters should be equivalent unless they are a component of the analysis.</u> When estimating operational energy use of building designs not in use yet, energy modeling software is employed. Many model input parameters pertain to the building products in the walls, floors, roofs, etc. and therefore the information needed overlaps with that needed for other life cycle modules. Some aspects of operational energy use are dependent on the behaviors of future occupants, such as use of lighting, shading, hot water, plug-in appliances, and heating and cooling setpoints. Other critical aspects of operational energy use are independent of the building structure, particularly the efficiency of HVAC and hot water equipment. Appliances are often specified in the late design stages (Ghattas, Gregory, Miller, & Kirchain).

Despite its large contribution to the environmental impact of a building and the considerable variability in modeling assumptions, the estimation of OEC is not strictly specified in whole building standards and PCRs. (ASTM) requires that the building designs under comparison have the same location (implicitly with identical temperature zones), the same orientation, and the use the same energy simulation tool on an hourly basis. The ISO standard for whole buildings, ISO 21931-1:2010, does not include operational energy use-relevant standards among its normative references. The European equivalent, EN 15978:2011, and the (International EPD® System) do reference EN 15603 though it's not clear if adherence to it is required.

<u>Input a common set of reference values as assumptions where appropriate</u>. To facilitate a common set of building operations parameters, reference values should be input as assumptions. For residential homes in the US, there is a set provided by the (Wilson, Metzger, Horowitz, & Hendron). For other types of buildings, EN 15603 and ASHRAE 90.1 Appendix G have guidelines. If the building design specifies some of these parameters differently than the reference values, such as including a solar panel array, the results with those inputs can additionally be reported.

Treatment of biogenic carbon

Biogenic carbon is carbon derived from biomass, in contrast to fossil carbon which is contained in fossilized material (ISO). For example, whereas biogenic carbon is contained in trees, fossil carbon is contained in coal. The carbon footprint of building products that are created from materials containing biogenic carbon, primarily wood, can be more complex to assess than building products transformed from other materials like metals and minerals.

The source of the complexity begins with the fact that trees uptake the greenhouse gas carbon dioxide via photosynthesis throughout their lives, and store much of it in the stem, branches, and roots. Wood products are then manufactured from the stem of harvested trees, the products are used, and the products decompose fully or partially over time after their end-of-life. A number of scenarios arise that need to be considered.

Many authors in recent years have considered how to properly account for biogenic carbon in forestry products. Helin, Sokka, Soimakallio, Pingoud, and Pajula (2013) thoroughly reviewed and contrasted the practices in 20 research articles and reports, along with directives. (Brunet-Navarro et al.) offer a succinct framing in their article reviewing 41 models that simulate the carbon balance of the wood product sector:

> “Wood product models are also used to estimate the greenhouse gas emissions derived from wood product use. Biogenic emissions are estimated though carbon stock changes. If the carbon stock increases, the wood product pool acts as a carbon sink; otherwise it acts as a carbon source. Decomposition of wood can occur under different conditions with consequences for the type of gas that is released. Decomposition of wood under aerobic conditions produces CO_2 emissions, while under anaerobic conditions it produces non-CO_2 emissions such as CH_4.”

Complex models of reality are the appropriate benchmark for assumptions about biogenic carbon. The challenge is to model the carbon stock changes and decomposition after end-of-life related to the wood product use. (Brunet-Navarro et al.) rate models based on their representation of reality, which requires high complexity. The complexity and associated data requirements can seem overwhelming, and it is tempting therefore to avoid details and create high-level assumptions. The test of the appropriateness of such a high-level approach is how well the assumptions approximate a complex model of reality.

Assumption of biogenic carbon neutrality too simplistic. Some situations may be a net carbon sink or net carbon source. *Biogenic carbon neutrality* is defined as the “balance of biogenic carbon uptake during growth of biomass and release during natural decay or incineration” (European Committee for Standardization). EN 16485 analyzes forestry impacts at a “landscape level” where decisions are made, and therefore considers that in a sustainably managed forest, total forest carbon pools are stable or increasing. In countries with certified sustainably managed forests, EN 16485 considers the wood to be carbon neutral.

Detrimental activities that result in deforestation and unsustainably produced timber are to be included in EN 16485, but it does not make specific mention of the possibility of methane gas that is released and not captured when wood is landfilled, whereas ISO 14067 does assert biogenic carbon neutrality except for the biomass’ conversion to gasses besides carbon dioxide.

Turning to PCRs based on these standards, guidance varies considerably. For instance, (Institut Bauen und Umwelt e.V.) produced core calculation rules and several documents with requirements for the EPDs for different wood-based products. The only related mention is similar to biogenic carbon language in EN 15804, that accounting reflects physical flows. (FPInnovations) produced a PCR for North American Wood Products. Its treatment of biogenic carbon follows EN 16485, but applies it to a North American context, stating "Consideration of the biogenic carbon neutrality of wood is valid for North American wood products as national-level inventory reporting shows overall increasing and/or neutral forest carbon stocks in recent years". In partnership with Athena Sustainable Materials Institute, they created spreadsheets for cradle-to-gate and cradle-to-grave EPDs "that provide[s] estimates for North American average end-uses and subsequent service lives, and the treatment they undergo at the end-of-life."

Based on the complex set of factors discussed below, we feel that the assumption of biogenic carbon neutrality does not provide sufficient nuance for proper assessment. In some situations, the results of an analysis may point to carbon neutrality, but it could be a net carbon sink or net carbon source.

The set of forest carbon assumptions should be equivalent for comparison. (Brunet-Navarro et al.) assert that all assumptions "should be reviewed when comparing or using results from different studies, so as to avoid incomparable conclusions." They highlight the importance of forestry modeling assumptions with the example of contradictory recommendations for maximizing forest carbon storage — models including bucking allocation (allocation of logs of different grades to different products) recommend long rotations, while those excluding it recommend short rotations. Forest conditions and management practices differ, so the forest parameters aren't expected to be set the same, but the framework followed and set of modeling assumptions included are.

Treatment of biogenic carbon intersects with several topics, including treatment of time, allocation, and treatment of end of life previously discussed. Several standards' and guides' approaches to these topics are included in Appendix 4.

Below, we make recommendations for current and future practice based on literature and standards. A list of factors for consideration includes the following:

- Reference situation for land use change
- Timing of emissions and sinks and time horizon
- Carbon storage in products
- Scope of forest carbon stock
- Approach to forest carbon stock estimates
- End-of-life

Reference situation for land use change

The reference land-use situation should be defined as 'no use' in attributional LCA. Helin et al. (2013) emphasize the importance of defining a reference situation for the land as a basis for comparison with what has taken place during forestry activities. The reference land use should be defined with support from guidance documents, and no credit should be given for non-human activities (consistent with LCA principles). In attributional LCA used in current practice, there should be a 'no use' reference situation which is the natural relaxation of the land; in consequential LCA it would be the alternative land use. (Sathre & O'Connor) note in their meta-analysis of studies on wood product substitution that their "**discussion of wood production in *managed* forests must be distinguished from the carbon balance effects of harvesting *primary* forests**. Conversion of primary (old-growth) forests to secondary, managed forests results in a loss of stored carbon from both biomass and soils, before the forest carbon stocks again reach dynamic equilibrium."

Timing of emissions and sinks and time horizon

Currently, the practical approach is to consider whether an activity occurred within the RSP. While the timing of emissions and sinks is important, it is currently not practical to do so in a detailed manner, and so the current static LCA approach should be followed despite shortcomings. In this approach, all of the activities that take place within the RSP are totaled and a fixed GWP factor is multiplied by that total. In this way, the timing of the emissions and sinks is not taken into account, and the time horizon is effectively that of the GWP factor.

Future: Moving to the use of dynamic LCA in the future will enable proper assessment of the timing of emissions and sinks. Relatedly, in dynamic LCA, (Levasseur et al.) have demonstrated that the timing and time horizon influence the overall outcome. They model a wood chair and its replacement across 100 years, and track the instantaneous and cumulative emissions and sinks as they evolve. They consider two modeling assumptions around carbon sequestration: it occurs before the tree is harvested versus it occurs after the harvest while newly planted trees are growing in its place. On a 100-year time horizon, the "before" scenario results in net carbon benefit while the "after" scenario does not; on a 500-year time horizon both scenarios result in a carbon benefit. These analyses further support the move toward use of dynamic LCA in future assessments in order to obtain more precise and accurate analyses to support policy goals.

Carbon storage in products

Carbon storage time period and effects should be reported separately. If the product is durable and intended to last many decades, that carbon storage could be considered a boon by delaying carbon emissions while the global community strives to cut them. If the carbon is permanently sequestered, that is certainly beneficial. If the storage is impermanent, though, the delayed carbon release but would impact future generations; quantifying a benefit for that delay is therefore a value judgement.

None of the standards currently factor this into the life cycle impact, but many suggest it be reported separately. We agree the treatment of carbon storage in EN 16485 section 7.6 which states that the "effect of timing of GHG emissions due to biogenic carbon storage may be Included as additional environmental information, for example on the basis or PAS 2050 or IPCC".

Future: Methods for estimating carbon storage should consider that only part of the harvested tree is stored in products. Interestingly, (Ingerson) demonstrate that 46% of the live tree becomes logging residue and another 22% is mill residue, resulting in 32% of the carbon in the live tree being stored in the wood product. The logging and mill residues likely transform into carbon dioxide much sooner than the wood products. Considering that the residues are causally related to the felling of the tree for the purpose of creating a wood product, an argument could be made that the carbon storage benefit should be adjusted to reflect the fate of the entire tree.

Scope of forest carbon stock

Forest carbon stock models should be inclusive of all terrestrial carbon stocks. Figure 3 presents CO2 sources and sinks in a forest. The main sink is photosynthesis leading to storage in the stem, branches, and roots, along with litterfall and root loss. Sources include various forms of respiration, dissolved carbon in the soil, and disturbances such as wildfires.

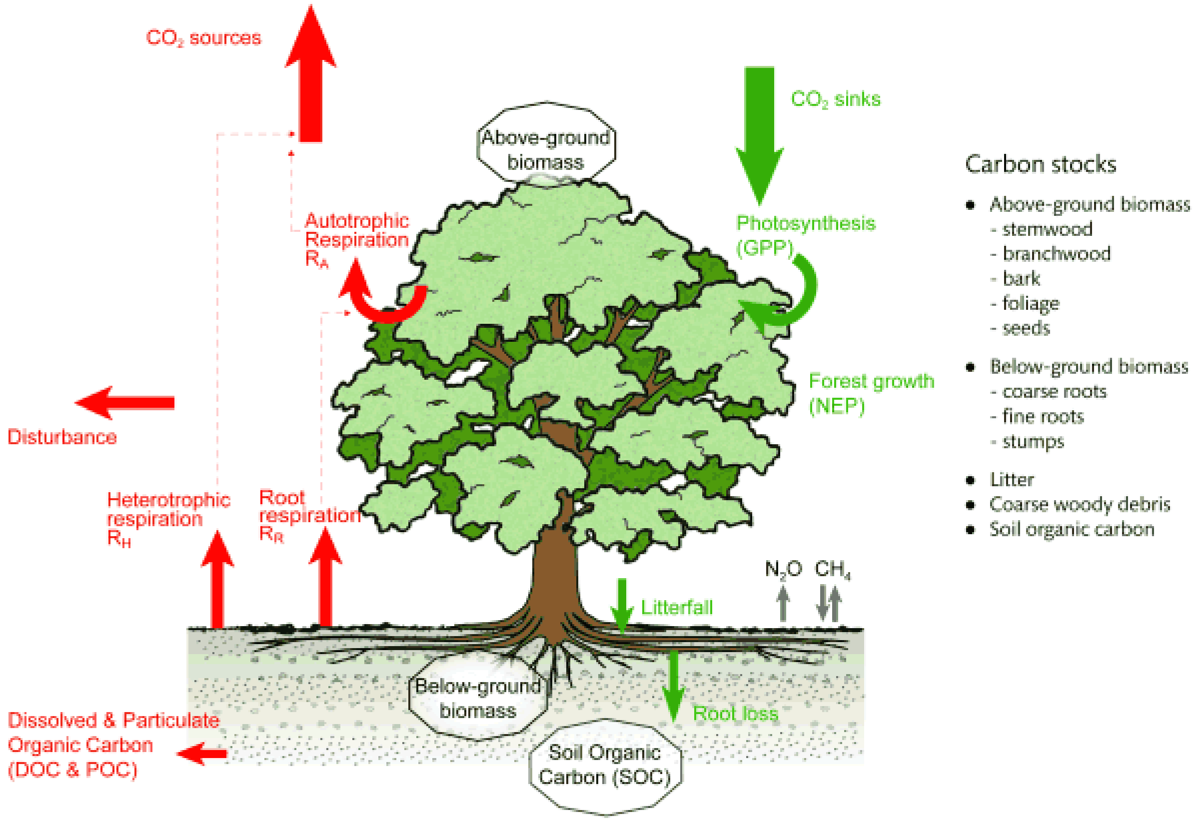


Figure 3: Forest carbon fluxes (Forest Research, 2016)

One of the questions Helin et al. (2013) asked of the documents under review was: “Does the approach consider the whole carbon stock of the forest or only part of it?”. They address the importance of considering the changes in soil carbon since soil and litter may contain half or more of the forest carbon stock. Most of the studies they reviewed included it, though some doubted its significance. Departing from this trend, EN 16485 (both a PCR and a standard for wood building products) states that excessive extraction of slash, litter, or roots is not causally linked to wood and excludes it from the assessment.

Approach to forest carbon stock estimates

Estimates should be based on a dynamic forest carbon stock model. Helin et al. (2013) discourage the use of default terrestrial carbon stock values in estimates, noting the “large variations in local terrestrial C stocks compared with the global default values.” Most of the studies they reviewed used dynamic forest models, consistent with the most detailed approach for assessment of carbon stock changes in the Tier 3 approach by the Intergovernmental Panel on Climate Change.

End-of-Life

The fate of a wood product at and beyond its end-of-life can have a considerable impact on its life cycle carbon balance. Wood may be reused or recycled several times before final disposal. Then, Brunet-Navarro et al. (2016) describe that it may be disposed of in an open dump with oxygen present leading to total decomposition back into CO_2, or if the landfill is sealed, a fraction of the wood decomposes into methane and CO_2. Methane is a potent greenhouse gas which some landfills recover and others vent. Relating this to carbon storage, wood that has not decomposed in landfills can be considered stored and part of the carbon stock. Wood may also be incinerated and generate energy in the process. The variety of fates emphasizes the importance of assessing and reporting scenarios.

Treatment of end-of-life

Differences in end-of-life (EOL) scenarios has been shown to influence life cycle results. Sandin et al. (2013) compared EOL scenarios for buildings with glulam beam and steel frames and observed significant differences in the life cycle results depending on EOL assumptions such as recycling versus incineration for the beams. Dodoo, Gustavsson, and Sathre (2009Dodoo, Gustavsson, and Sathre (2009) compare the post-use material management of concrete and wood frame buildings, taking into account factors such as the carbonation potential of crushed concrete and wood use possibilities. They also found considerable emissions differences between EOL scenarios.

Scenarios for end-of-life (EOL) need to be reported for buildings and building products. Decades in the future, it is likely that both regulations and technology will evolve, influencing the fate of building products. An accurate prediction of what fraction of building products will be landfilled, incinerated, reused, or recycled would be very helpful in improving the accuracy of LCA. In lieu of that, the best approach to estimate the impacts of processes that will occur many years in the future is to assess scenarios. As discussed above in the *Uncertainty Analyses* section, a range of scenarios can be developed and defined in each PCR.

Appendices

Appendix 1: Overview of Current Standards

Combination of building products and building operational impacts

To assess the impact of the whole building across its life cycle, information on the building products and the building operations are assembled. The standards have adopted a framework for categorizing the different stages of the lifecycle from A, production, through C, end of life; they also have a module D for impacts beyond the system boundary. In an ideal situation, declarations of all building products used would include all of the stages. In actuality, the standards only mandate that production be included, and set the other stages as optional, which can lead to improper summation. The operational consumption is assessed and added separately from the building products.

It is crucial to assess the impact of the building products and operational consumption jointly. The choice of building products will influence the thermal properties of the building, and therefore will influence the operational consumption. For example, thicker insulation will tend to decrease the heating and cooling requirements. Assessed separately, the additional material would be seen as solely a burden. Assessed jointly, the benefits of reduced operational impact would be clear. At this stage, tradeoffs between increased material impact and reduced operational consumption would be assessed for decision making.

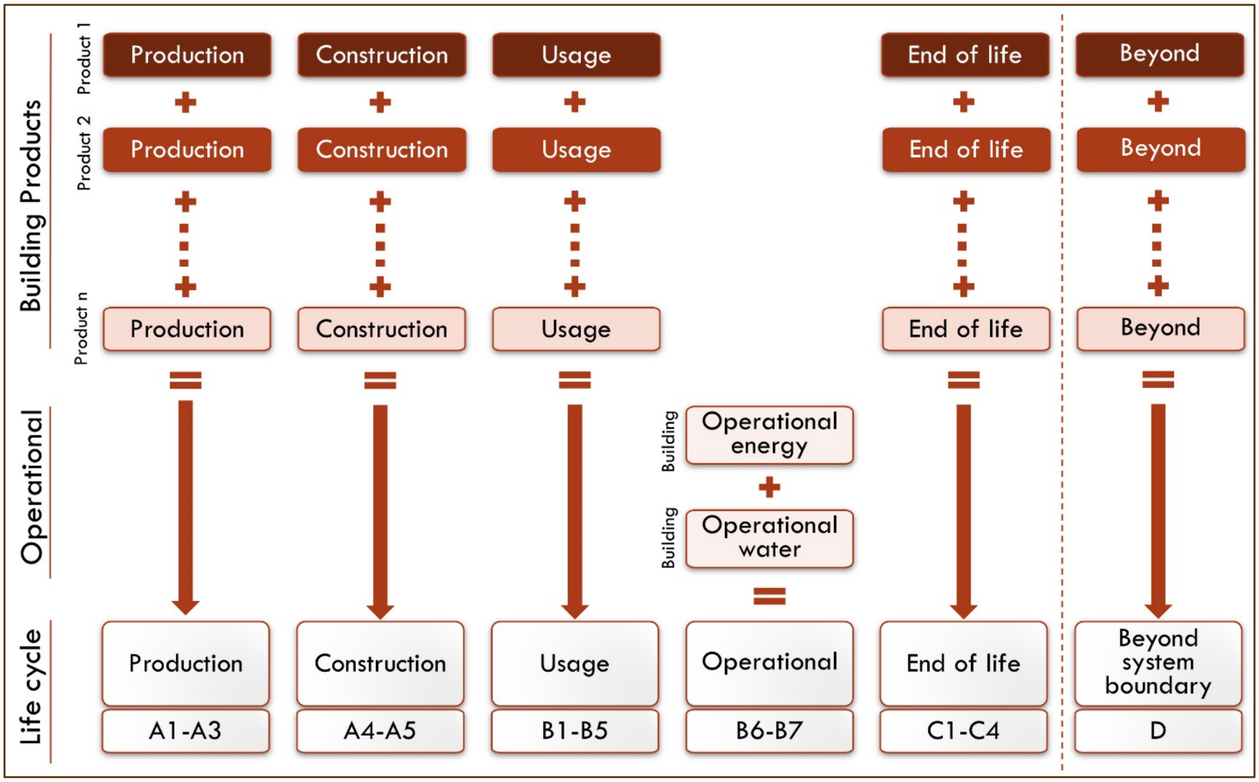


Figure 4 General approach in standards for capturing the environmental impact of building products and operational impacts across the building life cycle. The impacts of building products 1 through n are summed. The operational impacts are assessed at the whole building level.

Relationship between standards, PCRs, BPDs, and EPDs

The end result of the whole building LCA is sometimes referred to as a building product declaration (BPD) or environmental building declaration (EBD), which incorporate environmental product declarations (EPDs) and operational consumption data. BPDs are produced by the program operator, and follow product category rules (PCRs). Similarly, EPDs are produced by manufacturers subject to PCRs for products like wood, concrete, steel, windows, roofing, etc. Each EPD should contain the information for the life cycle stages depicted in Figure 4. PCRs are developed according to standards by program operators[1] in partnership with stakeholders.

The standards build on each other and become more specific. Whole building assessment standards and building product assessment standards are developed in accordance with building assessment framework standards, which are themselves building-specific interpretations of general LCA standards. Consumption of various forms of energy and water during building operations should be accounted for in accordance with standards for measuring or modeling them.

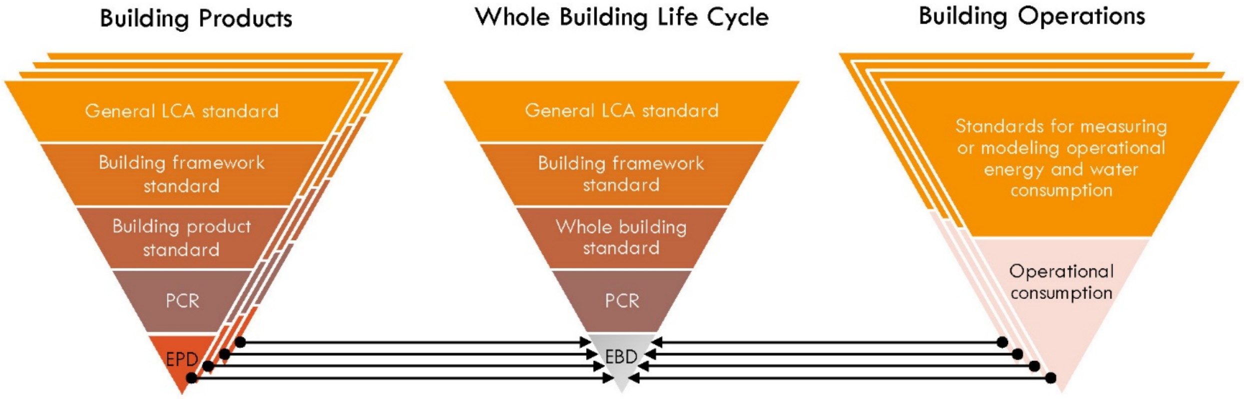


Figure 5: Relationship between standards, PCRs, EPDs, BPDs, and operational consumption for whole building LCA.

Overview of relevant standards

Table 2 provides the main standards pertaining to the environmental assessment of buildings and building products. A parallel hierarchy exists for international standards from ISO and European standards from the European Committee for Standardization (CEN). The methodological or framework standards apply not only to environmental assessment, but to social and economic assessment as well; however further standards on those aspects are not yet available.

The building standards guide the combination of the products and operational impacts depicted in Figure 4. ISO 21931-1 and EN 15978 provide guidance on the boundary and accounting of each life cycle stage (or module). Recently, ASTM E2921-13 was introduced to define criteria for ensuring comparability between whole building LCAs. As a four-page document, it does not go into great detail.

In the past decade, ISO 21930 and EN 15804 were created to guide PCRs for building products. As Figure 6 shows, EN 15804 was developed upon and after ISO 21930; many in Europe have used it as a

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[1] Visit the Product Category Rule Guidance Development Initiative for a list of Program Operators. http://www.pcrguidance.org/

replacement for ISO 21930, which is a valid standard but is currently in the process of being revised. The vast majority of building product PCRs reference one or both of these, as shown in Figure 7. EN 16485 is both a PCR and a standard for wood building products.

Table 2: Comparison between ISO and European standards related to whole building LCA

Standard Level	International standards (ISO)	European Committee for Standardization standards (CEN)

Building Framework Standard	• **ISO 15392**: Sustainability in building construction -- General principles
	• **ISO/TR 21932**: Sustainability in buildings and civil engineering works -- A review of terminology
	• **ISO 21929-1**: Sustainability indicators – Part 1: Framework for the development of indicators and a core set of indicators for buildings
		• **EN 15643**: Sustainability of Construction works
		  • Part 1 – Sustainability assessment of buildings. General Framework
		  • Part 2 – Assessment of buildings. Framework for Environmental Performance

Whole Building Assessment Standard	• **ISO 21931-**1: Framework for methods of assessment for the environmental performance of construction works – Part 1: Buildings • **ISO 14044**	• **EN 15978**: Sustainability of Construction works – Assessment of Environmental Performance of buildings – Calculation method

Building Product Assessment Standard	• **ISO 21930**: Environmental declaration of building products
	• **ISO 14044**
		• **EN 15804:** Environmental Product Declarations
		  • **CEN/TR 15941**: Methodology for selection and use of generic data
		  • **EN 15942**: Communication format business-to-business

Building Product Category Rules Standard		• **EN 16485**: Round and sawn timber – Environmental Product Declarations - Product category rules for wood and wood-based products for use in construction

In Appendix 2, Figure 6 traces the evolution of a suite of standards relevant to whole building LCA. While the vast majority of building-specific standards were introduced in the last decade, the ISO standards that lay the general framework for conducting any LCA, ISO 14040 and 14044, were established in 1997 and are on their fourth iteration. ISO 14025, established in 2000 and revised in 2006, guides the development of PCRs in general and is referenced by ISO 21930 on building products. It is sometimes used directly for building-related PCRs. Relatedly, the Product Category Rule Guidance Development Initiative (PCRGDI in this study) published a document in 2013 to supplement the international standards to address inconsistencies in PCRs. Figure 7 provides a count of building-related PCRs citing various standards.

The European Commission introduced the Product Environmental Footprint (PEF) guide in 2013, which was preceded by the International Reference Life Cycle Data System (ILCD) handbook in 2010. In response to perceived narrow focus of PCRs, there are PEF category rules (PEFCRs) under development which aim to be more representative and inclusive of products produced across an industry.

While the standards mentioned address multiple environmental impact metrics, another set of standards focuses squarely on the global warming impact. ISO 14067, BSI PAS 2050, and GHG Protocol Product Standard provide requirements for carbon footprint calculation and reporting.

Measuring the energy and water consumption after a building is in operation, or modeling it in advance, requires a very different set of guidance. At the international level, ISO 16346:2013 combines “results from other International Standards that calculate energy use for specific services within a building”, such as EN ISO 13790 for heating, cooling, and EN 15193 for lighting, etc. EN 15603 performs a similar function at the European level. As noted in the text, there are not strict requirements in the whole building standards that the operational consumption standards be followed.

Appendix 2: Evolution of relevant standards and use in PCRs

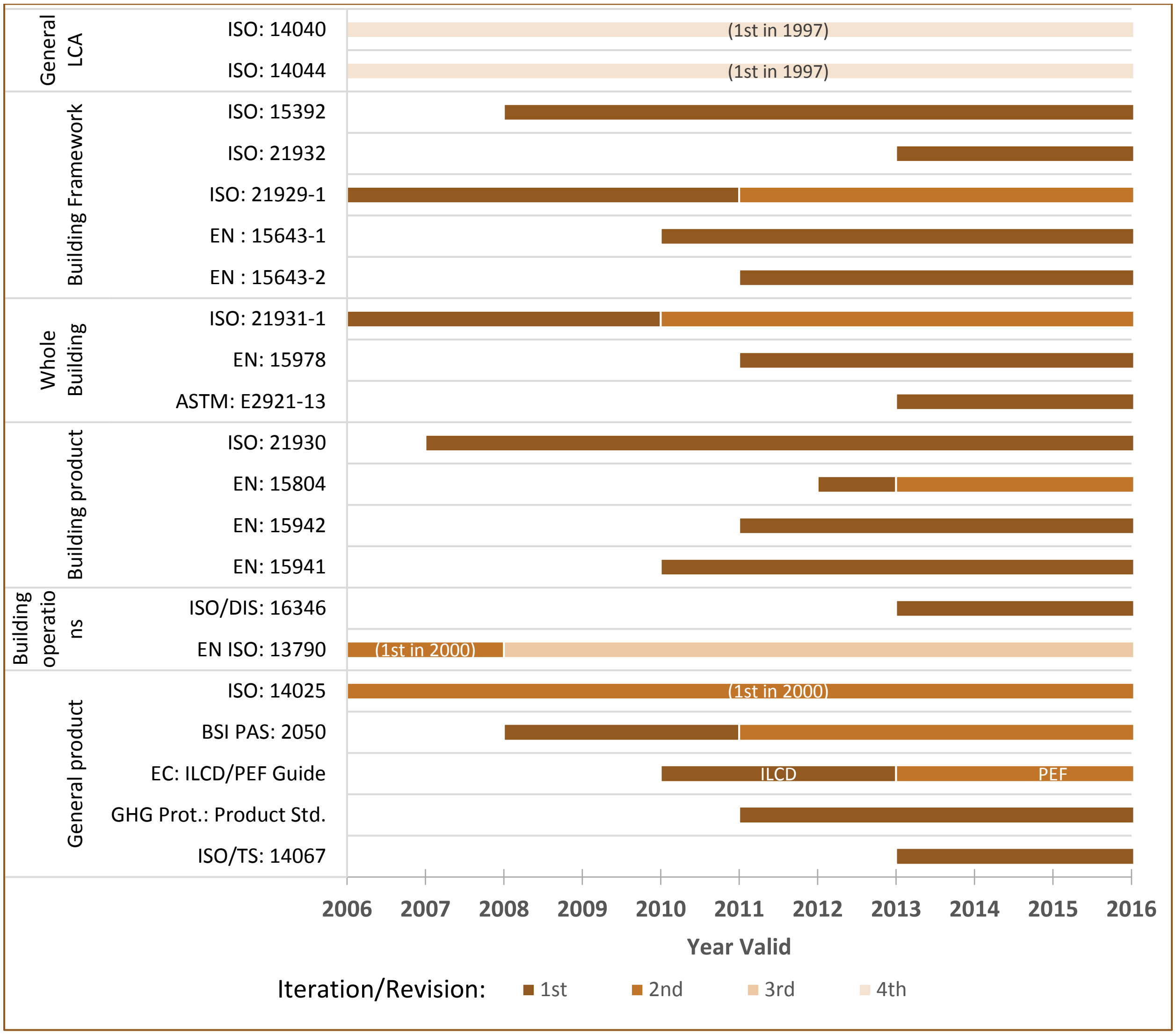

Figure 6: International and regional standards related to the LCA of buildings and building products, grouped by scope of standard. Color indicates the iteration of the standard, valid over given years.

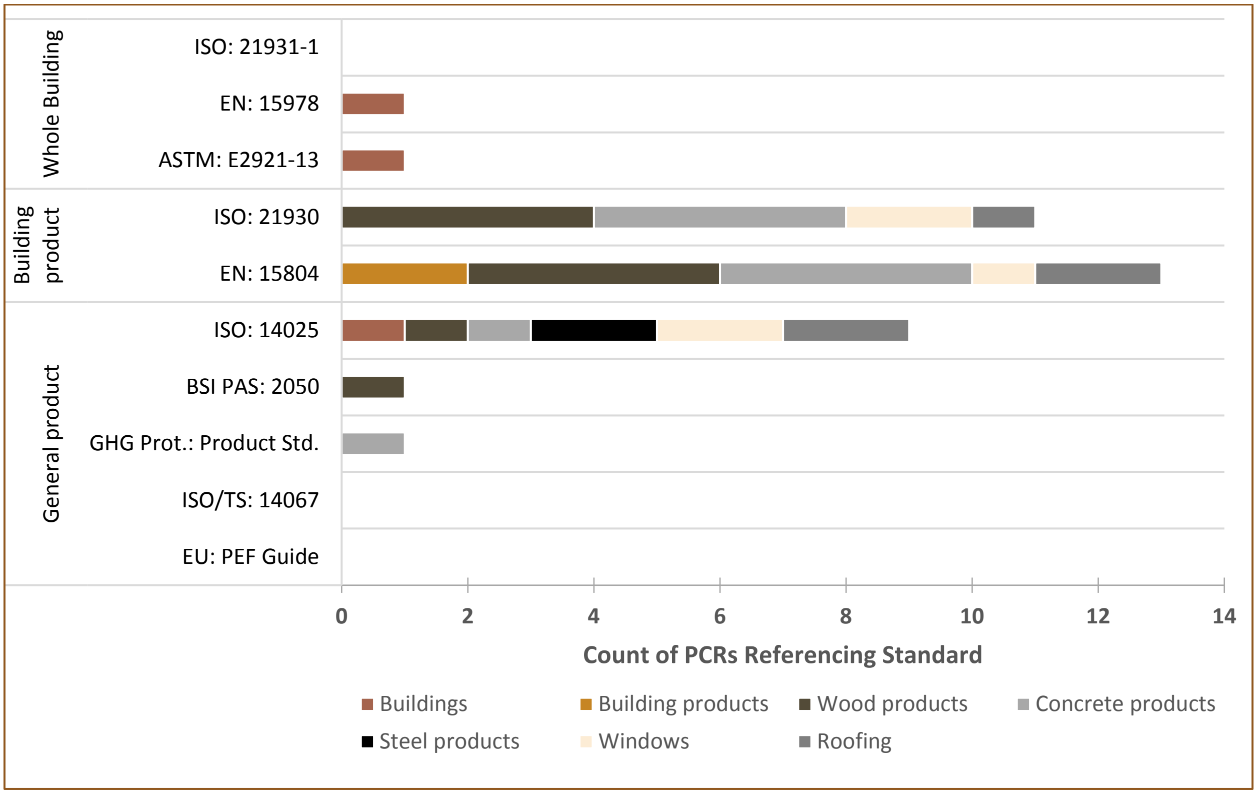

Figure 7: Count of PCRs found that reference the standards. The PCRs are categorized by the scope and type of product. LCA standards excluded because tend to underlie other standards and therefore effectively all PCRs.

Appendix 3: Details about additional standards

Table 3: Details about additional standards

Organization	Code	Recent Year	Title	Scope
ISO	14040:2006	2006	Environmental management -- Life cycle assessment -- Principles and framework	LCA
ISO	14044:2006	2006	Environmental management -- Life cycle assessment -- Requirements and guidelines	LCA
ISO	14025:2006	2006	Environmental labels and declarations -- Type III environmental declarations -- Principles and procedures	Product, EPD guidance
ISO	14067:2013	2013	Greenhouse gases -- Carbon footprint of products -- Requirements and guidelines for quantification and communication	Product, Carbon footprint
British Standards Inst. (BSI)	PAS 2050:2011	2011	Specification for the assessment of the life cycle greenhouse gas emissions of goods and services	Products, Carbon footprint
GHG Protocol		2011	Product Life Cycle Accounting and Reporting Standard	Product, Carbon footprint
European Commission		2013	Product Environmental Footprint (PEF) Guide	Product, Environmental footprint
ASTM	E2921-16	2016	Min. Criteria for Comparing Whole Building LCA for use with Building Codes & Rating Sys.	Buildings,

Appendix 4: Treatment of biogenic carbon in the standards

The state of the land before and after the wood is harvested is the focus of estimates of *direct land use change* and related *soil carbon change*. The consequences of the direct land use change on other land outside of the system is the concept of *indirect land use change*. If the product is durable and intended to last many decades, that *carbon storage* could be considered a boon by delaying carbon emissions while the global community strives to cut them but would impact future generations; quantifying a benefit for that delay is therefore subjective. The fate at end of life plays a big role in the overall net life cycle impact.

Table 4: Overview of treatment of Biogenic carbon, carbon storage, land use and soil carbon change in standards and guides

	Wood	**Building Product**		**General Product**				
Does this standard or guide address this issue:	**EN 16485: 2014**	**ISO 21930: 2007**	**EN 15804: 2012+ A1:2013**	**ISO 14025: 2006**	**BSI PAS 2050: 2011**	**GHG Protocol Product Standard: 2011**	**ISO/TS 14067: 2013**	**EU PEF Guide: 2013**
Biogenic carbon	Net zero carbon if country sustainably manages its forests	Not addressed	Reflect physical flows	Not addressed	Removal at most reflects carbon embedded	Include in total and separately	Include in total and separately	Report separately
Carbon storage	Report delayed emissions separately	Not addressed	Not addressed	Not addressed	Carbon is stored after 100 years	Report delayed emissions separately	Report storage time separately	Report storage time separately
Direct land use change	Include in accordance with IPCC	Not addressed	Not addressed	Not addressed	Include for 20 years or harvest prior	Include in total and separately	Include in accordance with IPCC	Include for 20 years prior
Indirect land use change	Include when IPCC procedure exists	Not addressed	Not addressed	Not addressed	Not included, considered in future	Not required, report if significant	Include when IPCC procedure exists	Not included currently
Soil carbon change	Stable in sustainably managed forests. Extraction of slash, litter, roots not included.	Not addressed	Not addressed	Not addressed	Exclude if not tied to land use change	Optional if can be reasonably estimated	Include when IPCC procedure exists	Exclude if not tied to land use change

Key:	Not addressed	Not required currently	Required currently

Table 4 above summarizes how the building product or general product standards and guides address these topics. As a PCR and standard, EN 16485 offers some guidance where lacking from the building products related standards on these issues, aside from a brief mention in EN 15804 that accounting reflects physical flows. Biogenic carbon and direct land use change are addressed and included in the general products standards and guides aside from ISO 14025. None currently require indirect land use change, citing lack of internationally agreed upon methods. Several encourage of soil carbon change if it is tied to land use change. EN 16485 states that excessive extraction of slash, litter, or roots is not causally linked to wood and excludes it.

Appendix 5: Details about PCRs

Table 5: Details about PCRs

Organization	Code	Year	Title	Normative Reference	Scope
International EPD System	2014:02 VERSION 1.0	2014	PRODUCT GROUP: UN CPC 531 BUILDINGS	ISO 14025:2006	Buildings
Athena Sustainable Materials Inst.	1st Edition	2014	Athena Guide to Whole-Building LCA in Green Building Programs	EN 15978:2011 ASTM E2921-13	Buildings
Bre	PN514	2014	Global PCR for Type III EPD of construction products	EN15804: 2012+A1:2013	Building products
IBU (Institut Bauen und Umwelt e.V.)			Part A: Calculation Rules for the LCA and Requirements on the Project Report	EN15804: 2012+A1:2013	Building products
ICC Evaluation Service		2013	North American Pressure-treated Wood Products	ISO 21930:2007	Wood products
FPInnovations	May 1, 2013 Version 1.1	2013	North American Structural and Architectural Wood Products	ISO 21930:2007	Wood products
European Committee for Standardization	EN 16485:2014	2014	Wood and wood-based products for use in construction	EN 15804: 2012, ISO 21930:2007, PAS 2050:2011	Wood and Wood products
IBU (Institut Bauen und Umwelt e.V.)		2014	Solid wood products	EN 15804: 2012	Wood products
ASTM		2015	INTERIOR ARCHITECTURAL WOOD DOOR LEAVES	ISO 21930:2007, partial EN 15804: 2012	Wood doors
Norwegian EPD Foundation		2012	Precast Concrete Products	EN 15804: 2012, ISO 21930:2007	Precast Concrete
Carbon Leadership Forum		2012	Concrete	ISO 14025:2006 and/or GHG Protocol	Concrete
WBCSD CSI	2013:02 VERSION 1.0	2013	UN CPC 375 CONCRETE	EN 15804: 2012, ISO 21930:2007	Concrete
ASTM		2014	Manufactured Concrete and Concrete Masonry Products	ISO 21930:2007, partial EN 15804: 2012	Concrete products
ASTM		2015	Precast Concrete	ISO 21930:2007, partial EN 15804: 2012	Precast Concrete
China Steel Corporation		2010	Carbon steel and carbon steel products	ISO 14025:2006	Steel & Steel products
Associazione tecnica per la promozione degli acciai sismici per cemento armato (SISMIC) & Life Cycle Engineering		2011 *expired*	CPC Class 4124 STEEL FOR THE REINFORCEMENT OF CONCRETE - WELDABLE REINFORCING STEEL (EN 10080)	ISO 14025:2006	Reinforcing steel

Organization	Code	Year	Title	Normative Reference	Scope
Norwegian EPD Foundation	NPCR 014 rev1	2013	Windows and doors	ISO 14025:2006 ISO 21930:2007 EN 15804: 2012	Windows
Earthsure	v 1.02	2015	Cradle to Gate Window Product Category Rule	ISO 14025:2006 ISO 21930:2007	Windows
Norwegian EPD Foundation		2012	Roof waterproofing	ISO 14025:2006 ISO 21930:2007 EN 15804: 2012	Roofing
ASTM		2014	Asphalt Shingles, Built-Up Asphalt Membrane Roofing, and Modified Bituminous Membrane Roofing	ISO 14025:2006, , partial EN 15804: 2012	Roofing

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