The Benefits of a Whole Building LCA or Total Carbon Analysis:
Using Embodied and Operational Carbon to Holistically Analyze Building Emissions

PREPARED BY WAP SUSTAINABILITY FOR THE AMERICAN CHEMISTRY COUNCIL

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Whole building life cycle assessment, or WBLCA, estimates the net impact of constructing and operating a building. Recent industry trends emphasize material selection based on embodied carbon reductions, which could undermine the potential of continued operational carbon reductions and a holistic strategy to address building sector decarbonization. In lieu of a WBLCA, an interim "total carbon" approach can serve as a step toward better decision making. This approach quantifies a material or product's net emissions of embodied carbon and operational carbon benefits realized during a building's operational phase. When a material's total carbon impact is considered, the resulting building design begins to optimize both embodied and operational carbon reduction opportunities. This interim strategy prepares designers to further leverage WBLCA as tools and methodologies improve.

In building and construction, greenhouse gas (GHG) emissions (or "carbon impacts") are often differentiated into two categories: Embodied Carbon (EC) and Operational Carbon (OC). EC is usually discussed at the product level, while OC is usually associated with the building during its use phase.

The buildings sector has been focused on operational energy savings in buildings for the last couple of decades. Recently, that focus has shifted to reducing the embodied carbon impact of buildings and building materials. This shift is influencing emerging policy and procurement requirements that reward those buildings and building materials that demonstrate the lowered global warming potential (GWP) impacts. However, basing policy or procurement decisions on the single attribute of carbon could result in regrettable substitutions or even increased life cycle carbon emissions if not implemented wisely.

The optimal WBLCA and "total carbon" approaches estimate a building or material's embodied carbon and operational carbon use and savings, presenting a combined result. This holistic perspective and approach reframe more accurately depicts the building or material's total life cycle impact.

Therefore, utilizing a WBLCA approach for buildings or total carbon approach for materials closes the gap toward comprehensive carbon reduction opportunities and should be the preferred method used for smart policy and procurement requirements.

Definitions

Embodied Carbon (EC): Estimated greenhouse gas (GHG) emissions of a product, material or building that may be associated with material extraction, manufacturing and transportation, construction, maintenance, replacement or repair, demolition or deconstruction, and disposal.

Operational Carbon (OC): Estimated greenhouse gas (GHG) emissions and emissions savings that are associated with operational energy consumption of the building's systems during the building's use.

Total Carbon: Estimated net of greenhouse gas (GHG) emissions from a product or material's embodied carbon and emissions savings attributed to the operational carbon benefits realized after installation and during the building's use.

Whole Building Life Cycle Assessment (WBLCA): Estimated net of greenhouse gas (GHG) emissions and emissions savings attributed to a building's summed embodied carbon and operational carbon

WBLCA: Powerful Capabilities, Unlocked Potential

WBLCA in its full and realized form is the most accurate carbon accounting method, especially when all building materials are included. But best practices in WBLCA methodology and data quality from all material sectors and their supply chains are still improving. As the methodology and data mature, current and future calculation tools will need to manage increasingly complex data and computational requirements. WBLCA practitioners must also have a reasonable level of life cycle assessment (LCA) knowledge and judgment to complete and interpret the results of the assessment.

Due to the complexities of this method, some firms use an approach referred to as WBLCA, but they are only assessing a portion of the building. For example, they may focus on the embodied carbon of structural elements of the building and the resulting operational energy savings alone and not all of the materials in the building. This abbreviated approach recognizes that the structural components of buildings are usually carbon-intensive and may be the best available opportunity to make significant reductions. However, including a full bill of materials list in a WBLCA would provide a more accurate total carbon approach by considering embodied and operational carbon of the building and all its materials and their estimated impacts throughout all life cycle stages.

A comprehensive WBLCA unlocks the potential for better-informed design and procurement decisions. To get there, we need to improve data quality and availability through stakeholder collaboration, increased education, and experience.

Until WBLCA methodologies, tools and knowledge improve and become more widely available, a total carbon approach is the next best option. It is a sensible step forward in the absence of WBLCA capabilities and considers the embodied carbon and operational savings of materials. Some Building Envelope Thermal Insulation EPDs include a calculation of operational carbon benefits in the use phase in Section 7, Additional Environmental Information. There currently are no set PCR rules for conducting these calculations.

Figure 1. Whole building life cycle assessment evaluates the net GHG emissions and emissions savings attributed to a building's summed embodied carbon impact and operational carbon impact.

Meaningful Policy for Decarbonization is Important

The global building floor area (the aggregate area of every floor in a building, globally) is expected to double by 2060, particularly in the Global South and other rapidly urbanizing regions, making carbon impacts increasingly important.[1] At the same time, much of this new floor area and many existing buildings will still rely on non-renewable energy sources and inefficient energy transmission and distribution in grid operations. A total carbon strategy is needed to reframe decision-making, reevaluate decarbonization strategies in design and construction and help identify materials and construction practices to optimize building energy efficiency and limit the influence of energy regardless of its source.

Due to assumed reductions in operational energy reductions and renewable energy production increases, some believe that by 2050, half of the emissions from new buildings will be attributed to embodied carbon sources and the other half from operational carbon sources.[2] Even though we have a long way to go, the world's energy grids are slowly being transformed, and will place a greater importance on materials. Although operational carbon is responsible for most carbon emissions of new and existing buildings today, it is understood that with grid improvements, embodied and operational carbon will reach a more equal share of carbon emissions responsibility. As a result, both embodied and operational carbon impacts are the focus of many current decarbonization strategies.

1 UN Environment and International Energy Agency (2017): Towards a zero-emission, efficient, and resilient buildings and construction sector. Global Status Report 2017.
2 Why the Built Environment? Architecture 2030. Accessed May 15, 2023. https://architecture2030.org/why-the-building-sector/

Total Carbon: Reducing Embodied Carbon and Operational Carbon Through Informed Material Selection

Recent innovative building technologies demonstrate more efficient methods of design, construction, and operation, but transitioning to a net-zero carbon sector remains a complex technical challenge. However, we can start making better-informed material and design choices by incorporating a total carbon approach to significantly reduce embodied material and operational carbon impacts.

The early design process primarily focuses on the building structure and evaluates the embodied carbon impacts of material options such as wood, steel and concrete. Often missing from this approach is a consideration of how these materials contribute to energy use reduction or how they optimize building performance in the building use phase. This is also true when evaluating thermal envelope design. For example, building insulation helps optimize the thermal efficiency of a building's envelope, HVAC, and piping systems, which reduces the building's carbon footprint through lower heating and cooling energy consumption. This is especially important where access to low-carbon energy sources is and continues to be limited, which is currently still most of the Midwest and the Southeast Sunbelt (primarily Georgia, Alabama and Mississippi).[3]

Selecting materials with lower embodied carbon without sacrificing operational efficiency or other important performance characteristics is the goal of the total carbon decision-making process. A fully optimized building envelope enables the efficient use of energy sources and mitigates the influence of energy grid performance. Combined with improved grid operations like the use of renewable electricity to manage peak utility load demand and support zero energy building goals, choosing optimized materials leads to positive impacts throughout the building life cycle. Material specification also encourages enhanced building design strategies while discouraging compromises, such as carbon offsets used to compensate for a building's operational carbon, that may delay meaningful progress and cost a significant amount more than necessary.

Figure 2. Total carbon of a material evaluates the net GHG emissions from a product or material's embodied carbon and emissions savings attributed to the operational carbon benefits realized after installation and during the building's use.

The material selection or procurement phase of a project usually considers the CO_2 equivalent emissions reported in Environmental Product Declarations (EPDs) (as Global Warming Potential or GWP) of a given product category to evaluate the lowest, or lower embodied carbon options. This practice can significantly influence the procurement process and is susceptible to potential biases in tools and databases, such as overrepresentation of available products in a specific market and a lack of user guidance and interpretation that should supplement decision-making at this stage. EPDs are only comparable within the same product category and when other key characteristics of the underlining LCA are consistent.

EPDs and LCAs should be coupled with an assessment of alternative material or product performance attributes and durability. Product category rules (PCRs) that dictate the completion of a valid product LCA and EPD may specify different functional units (and therefore expected product lifetimes) for product systems that fulfill the same function in the building. For example, when choosing the entryway flooring for a high traffic visitor center, the durability and longevity of the product should be highly factored into the choice as the longer lasting product will almost certainly have a higher GWP than a rapidly renewable option, but when considering the replacement requirements compared to the alternative, it becomes obviously more advantageous to choose the longer lasting product.

Figure 3. Product Category Rules (PCR) dictate the completion of a valid material or product life cycle assessment (LCA) and environmental product declaration (EPD).

3 Emission Rates. eGRID Power Profiler. United States Environmental Protection Agency. Last Updated on June 5, 2023. Accessed on June 13, 2023. https://www.epa.gov/egrid/power-profiler#/

These attributes can be vital to the performance of the building and contribute to reductions of carbon during the building's operational phase as well as product durability — and reduce or entirely remove the need for product replacement during the building's lifetime. These benefits might be overlooked if focusing solely on CO2 equivalent emissions reporting between product categories, a methodology that still faces data quality issues.

A holistic consideration of how materials behave when the building is operational and how they influence energy or carbon consumption is necessary to sufficiently measure the environmental impact. Lowering energy use means a reduction in environmental impacts of the energy source and grid conditions supporting the building.

Moving Toward True Carbon Reduction Strategies with WBLCA

In conducting a WBLCA, a practitioner can capture a snapshot of a building at a specific point in time (such as at certificate of occupancy, design, or construction) to account for the materials used in construction and estimation of its operational energy use. A WBLCA could also be done on a building that has been in use for several years and could account for all materials used over its current lifespan and utilize real operational energy numbers. ISO standards, as well as computational tools, have evolved over the years to reinforce WBLCA as the most comprehensive approach to quantify potential and actual environmental impacts of a product or service — in this case a building's life cycle impacts.

However, as the use of WBLCA tools increases, the complexity of the analyses and variables grow. With the increasing number of available EPDs from product manufacturers, a healthier view is being taken towards data quality and comparability. The continuous improvements of best practices in WBLCA signal the commitment to leverage this methodology to make informed and optimized decisions toward decarbonization of the built environment.

The results from WBLCA studies require clarification and proper understanding of their interpretation and use. One area for improvement is the identification of impact hotspots that pinpoint top opportunities for carbon impact reductions. As computational methods improve, we will have better capabilities to make iterative changes to a model and see how both embodied and operational carbon impacts are affected. Along with developing guidelines and judgments for interpreting these results, a practitioner could address opportunities without overlooking other carbon-intensive parts of the building life cycle, particularly indirect emissions such as fuel source composition. For example, choosing lower embodied carbon insulation could increase energy usage of the mechanical, engineering and plumbing (MEP) systems if the insulating capacity is affected. Through a holistic total carbon approach and improved tools that cater to technical and non-technical designers alike, more of these winning opportunities can be identified and implemented in a project. Above all, we should seek to avoid burden shifting between embodied and operational carbon results that may lead to diminished potential for addressing total carbon reduction opportunities.

Conclusion

As WBLCA tools and methodologies improve and companies develop more LCAs and EPDs, a total carbon approach is poised to become the cornerstone of WBLCA study and interpretation — paving the way for the development of highly capable tools for WBLCA analyses and managing the environmental impact of our built environment.

Progress is being made but until WBLCA becomes the preferred method for quantifying carbon emissions from the built environment, a total carbon strategy will help practitioners enact and internalize the perspective needed to discern and interpret WBLCA results to support design flexibility and recognize a broader set of solutions that promote decarbonization goals.

Utilizing both total carbon and WBLCA methods promotes and enhances collaboration among stakeholders such as architects, engineers, builders, policymakers, and researchers, and affirms the importance of a coordinated effort to realize wise and informed carbon reductions in the built environment. Collective stakeholder engagement will also incentivize the study and creation of more reliable data, which will improve the tools and methodologies used to inform WBLCA.

The perspective and capabilities to deliver on accelerated decarbonization strategies are rapidly coming together. Coordinating a collective shift to total carbon and WBLCA approaches will equip the built environment's industries to effectively address its share of carbon emissions.

The Building Blocks of Carbon Accounting:
The Role of Product Category Rules, Life Cycle Analysis, and Environmental Product Declarations

PREPARED BY WAP SUSTAINABILITY FOR THE AMERICAN CHEMISTRY COUNCIL

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Environmental product declarations (EPDs) are increasingly utilized for product comparison and procurement decisions regarding building materials such as “Buy Clean” policies. Important context from their supporting life cycle assessment (LCA) studies are not included in the EPD and user guidance to properly compare products for material selection is lacking. Forthcoming product category rules (PCRs) and guidance for stakeholder development and input for PCR creation address some discrepancies that will improve comparability of EPD data. As technology improves, digital EPD generators that automatically administer PCR criteria will accelerate fair EPD generation and comparison. Quality PCRs will help ensure that results can reliably inform users seeking EPDs for the current carbon accounting for various use cases.

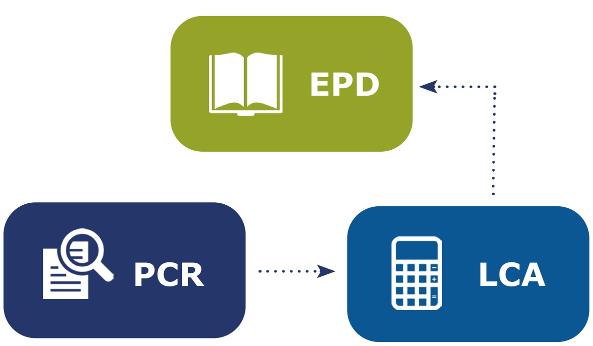
Building Blocks Guide EPD Development

Building regulations, policy, codes, and market trends are increasingly focusing on reducing the environmental impact of materials and products. Life cycle assessment (LCA) is a method used to assess environmental impacts throughout the life cycle of a product from raw material extraction through materials processing, manufacturing, distribution, use, repair and maintenance, and disposal and/or recycling.

The results of an LCA are rarely made public due to proprietary information around product formulation, production processes, and other manufacturer data that are included in the analysis. The proprietary data and analysis in an LCA model are usually not included in the environmental product declaration (EPD). An EPD is a public-facing, transparent, third-party verified summary of the LCA results. It is based on an underlying LCA and developed in accordance with ISO 14025 (and ISO 21930 or EN 15804 for construction products and services). The EPD is intended to provide a transparent and objective summary that communicates the results of the underlying LCA for industry users. EPDs are voluntary for most building projects, but EPDs are becoming increasingly common as tools for building material and product procurement requirements, specifications, and even some building code compliance.

Through a standards-like format, product category rules (PCRs) communicate requirements, guidelines, and expectations for applying LCA methodologies to a specific product type and its supply chain. The PCR should dictate how to conduct the LCA and what is or is not included, including guidance for data selection and calculations. In theory, if all LCAs are done the same way and in accordance with the PCR, certain variables and bias are better controlled and/or at least reported. In practice, most existing PCRs do this to an extent, but there is room for improvement.

These building blocks of environmental impact disclosure are interrelated and dependent on one another for the development of quality and consistent data reporting. Reliable PCRs are needed for reliable LCAs. Reliable LCAs are needed for reliable EPDs.



Product Category Rule (PCR): A standardized set of rules that set requirements, guidelines, and expectations for a life cycle assessment (LCA) for a specific product category or process.

Life Cycle Assessment (LCA): A method to assess environmental impacts throughout the life cycle of a product from raw material extraction through materials processing, manufacturing, distribution, use, repair and maintenance, and disposal and/or recycling.

Environmental Product Declaration (EPD): A public-facing, transparent, third-party verified summary of a life cycle assessment (LCA) developed in accordance with ISO 14025, and ISO 21930 or EN 15804.

Data Quality: Current Issues in LCA and EPD Comparability

Depending on the product or material and its governing PCR, EPDs will contain varying levels of detail, including assumptions, type of data gathered, and other relevant aspects of the supporting LCA. Differences in PCR development and guidelines have led to inconsistent EPD quality and specificity. The governing ISO standards give authors of PCRs (i.e. EPD Program Operators) significant flexibility in terms of what should and should not be required. This makes it harder to optimize the architectural design and specification decisions for decarbonization. To improve data quality, PCRs could require specific data to be developed and reported in a more consistent manner for each product category. This will enable the development of LCAs that are more accurate and more comparable for products in the same product category.

The American Center for Life Cycle Assessment (ACLCA) has recognized the opportunity for PCR improvement and developed guidance to inform practices for writing PCRs. First published in 2013, an updated guidance document was released in 2022 and acknowledges recent demand for EPDs and their communication of environmental impact data, particularly embodied carbon impacts as represented by global warming potential (GWP).[1] To create the EPDs that have the most consistent basis for comparison, we need to improve PCR guidance for life cycle assessments.

A PCR is intended to standardize EPD data to promote consistency, and in some cases, comparability of compliant EPDs within a product category. As a result, published EPDs serve as de facto user references for the estimated environmental impacts across the product's life cycle. To put it simply: EPDs are summarizing the environmental impact a product has, like a nutrition label does for health impacts of food. Because of this, they are being used increasingly in procurement decisions. For a manufacturer, the creation of an EPD helps benchmark the impacts of a product for the purpose of product optimization and innovation improvements.

Results generated by LCAs and communicated through EPDs are being used to inform procurement decisions and serve as data sources in larger assessments such as whole building life cycle assessment (WBLCA) because buildings continue to be a significant source of global greenhouse gas (GHG) emissions. Currently most emissions result from building operations, but the role of embodied carbon will continue to increase as we improve operational efficiency and achieve net zero buildings. To quantify the carbon impacts of a building, information on the impacts of the building materials must be included for all materials and products in a responsible and accurate manner.

Improving the consistency and quality of EPDs would inspire confidence in their use to make important decisions. While many believe that EPDs should be comparable when their underlying LCAs follow the same PCRs, some aspects of these governing rulesets could and should be further defined and aligned to improve the basis for comparisons between products.

Just as PCRs, LCAs and EPDs build on one another for environmental impact data reporting and their variability builds on one another as well. PCR guidance that lacks adequate specifications and differences in LCA inputs and modeling can lead to large error bars in the data summarized in an EPD. This is then exacerbated by tools or databases that put inconsistent data side by side and promote it as comparable. Care must be taken to understand if EPD data is consistent enough to be looked at side by side, especially when important design decisions are being made as a result.

LCAs are developed in accordance with ISO Standards 14040 and 14044. Additional country- or industry-specific standards may apply. Completing an LCA that enables broadest applicability requires conformance to the governing ISO standards and a general adherence to common LCA practices in the marketplace, particularly if industry-specific guidance is available. This encompasses the gathering of a large amount of data for material and process inputs and outputs. This data is needed to estimate the environmental impacts through LCA calculations. The result is an LCA report, which comprehensively documents the data considered and the process that was followed to generate the results of the assessment. Its format as outlined in ISO 14044.

ISO 14040/44 does not require a critical review for non-comparative LCAs, though developers of the LCA may request either an internal or external single expert review, to increase validity and acceptance of the results. If the LCA supports an EPD, it will be reviewed as part of the EPD verification process. Comparative LCA reports must be critically reviewed by at least three external reviewers – typically referred to as a critical review panel. LCA reports are technical in nature and include judgments, assumptions, decisions, and critical feedback that is usually beyond what a general user needs to know or is equipped to adequately understand.

1 2022 ACLCA PCR Guidance – Process and Methods Toolkit. Version 1.0. Published May 25, 2022. American Center for Life Cycle Assessment. https://aclca.org/wp-content/uploads/2022-ACLCA-PCR-Guidance_v1_Introduction_05252022.pdf.

The Role of Product Category Rules in Promoting EPD Consistency

The American Center for Life Cycle Assessment's (ACLCA) PCR Guidance (2022) identifies and summarizes three primary use cases of EPDs.[2] As "Buy Clean" legislation expands, a range of practical use cases have emerged with different accountability expectations. They are:

1. Transparency

EPDs provide transparency to the data collected. For example, EPDs allow clarity around what life cycle stages are being communicated, the source for emission factors used to calculate the impact, and any underlying assumptions. In this use case, the user may be interested in how the model was developed and in understanding where improvements can be made that impact the product life cycle, but in this case the EPD and its results are not intended for the purposes of procurement or decarbonization decisions.

2. Procurement

The use of EPDs to support procurement decisions requires a greater level of specificity of LCA model parameters, data quality parameters, and life cycle stages in the PCR guidance. For example, a PCR might prescribe the use of publicly available background databases with data quality assessment for more consistency and comparability when primary data is not available. Controlling the variables reduces differences in modeling and assumptions and can contribute to a greater level of consistency and quality than EPDs intended for transparency uses alone. Users who intend to use EPD data for procurement need reliable data to help choose the product that meets decarbonization goals in addition to design goals.

Eliminating discrepancies and increasing consistency of EPDs through PCR development is becoming more critical with the growing interest in environmental impact data for public and private procurement and decarbonization decisions. Therefore, consistent, and scientifically accurate PCR development and use for the purpose of executing quality LCAs is incredibly important. This will minimize inconsistencies and increase comparability that can support all three of the use cases discussed above. ACLCA's PCR Guidance – Process and Methods Toolkit (2022) provides a list of criteria that ACLCA contends a PCR must or should include to meet the rigor required for the identified use cases, and for material specifiers to understand and identify EPDs that meet the requirements of their projects. Its publication represents a significant advancement toward resolving major discrepancies between PCRs and their LCAs to improve the data consistency across the use cases of the EPD.

3. Data Source

EPDs and their results can be used as data points that are integrated directly into a WBLCA to inform engineering and design decisions. Ideally, documentation of the notable differences in methodology or specificity is published either in the primary PCR's General Program Instructions (governance document) or as supporting documentation. Users need to integrate reliable data points into a larger LCA model of a building and understand how changes in quantity or material type affect the embodied and operational carbon impacts of the building, and how impact reductions could be optimized.

Adhering to a standardized format for EPDs as prescribed by ISO and EN standards requires the elimination of some details contained in the LCA report that make the judgment and rationale used in the analysis transparent. Without rules for these judgments, the resulting analysis would be left to subjective interpretation and reduce comparability. While some data may be irrelevant to the reporting fields of the EPD, other LCA data may be considered proprietary. Varying amounts of important context may be left out of the EPD in either case. In theory, PCRs define parameters and prescribe consistent reporting methods with the goal of reducing discrepancies and increasing comparability. In practice, PCRs have been inconsistently developed. This is due to several factors including the wide variety of organizations that author PCRs, time and attention given to development, level of detail, differences in development guidelines, experience and expertise level of stakeholders, and cost invested in PCR creation.

2 2022 ACLCA PCR Guidance – Process and Methods Toolkit. Version 1.0. Published May 25, 2022. American Center for Life Cycle Assessment. https://aclca.org/wp-content/uploads/2022-ACLCA-PCR-Guidance_v1_Introduction_05252022.pdf.

Additional Improvements for Increased EPD Consistency

Below are some aspects of life cycle assessments that would benefit from higher levels of specificity in a PCR to promote EPD consistency and comparability. Following the publication of ACLCA's PCR guidance, program operators and their stakeholders in PCR development can apply the recommendations to existing and forthcoming PCRs to instill greater confidence in EPDs meeting the rigor of current and emerging use cases.

Background Data

Availability and cost of background data for life cycle assessment is a persistent issue. Acquiring primary data from suppliers, while the best case for accurate and reliable environmental impact results, can be an arduous process. Certain suppliers consider this primary data proprietary and may not want to release it, even to their customers under NDA. Industry data sets are usually only accessible through subscriptions or licenses to a database. Poor availability of primary background data can lead to the use of "best available" data that is generalized and only partially representative of the study's conditions, which adds to the uncertainty and inconsistency of LCA results.

Additionally, many EPDs do not specify how much or which data should be primary and supplier-specific vs. average or generic data. If the relative composition of supplier-specific vs. generic data were identified and described, EPDs would more clearly communicate the assumptions made in the underlying LCA. Some PCRs are testing the practice of prescribing specific data sets to be used in the LCA model, as recommended in ACLCA's 2022 PCR Guidance. The expansion of this practice along with an increase in free and open access data sets could improve consistency and data availability. Publicly available data would lower cost burdens and support the increased use of consistent primary data. It could also resolve differences in data quality indicators, such as completeness, consistency, accuracy, transparency, and relevance by utilizing the same basis for calculations and appropriate methods to handle data gaps and variability. This could however create a new issue. If everyone in a product category is using the same exact data and is not allowed to differentiate with their own primary data, manufacturers would not be able to demonstrate the actual environmental impacts of their differentiated products.

Boundary Conditions

While a PCR usually describes the boundary conditions of the LCA study, it often falls short of specifying what inputs or processes should or should not be included. For example, manufacturing and facility practices like space lighting and sub-metering of utility usage are not always stated clearly or consistently. In addition, different industries find some ancillary data important or not for their specific needs. This leads to varying levels of detail between PCRs and their EPDs.

Modeling Assumptions

PCRs commonly prescribe assumptions to be used in the LCA model when there is a lack of data or if data quality requirements are not met. LCA and EPD comparability within a product category can be hindered if different models use different assumptions. In these cases, practitioners must use their judgment and choose what they think is most appropriate, which can result in differences in the reported impacts. For example, one LCA practitioner may choose to deem a manufacturing function outside of the boundary, while another LCA practitioner may deem it within the boundary. Allocation is the process of apportioning and assigning the inputs and outputs of a system, and their associated impacts, to its products and co-products. Some industries use supply chain specific allocation while others use economic allocation, which can lead to significantly different results. While one allocation practice may be required in a particular sector, some collective requirements or prescribed conservative assumptions can help close these gaps and enable more consistent and reliable LCA and EPD comparisons.

Conclusion

PCRs can vary significantly and there is often no single correct set of requirements for PCRs across various categories. However, writing PCRs with a strict scope, clearly defined background dataset requirements, and explicit assumptions allows program operators and industry participants to maximize the reliability and comparability of their LCAs and EPDs. It levels the playing field for LCA practitioners, creates clear incentive structures for driving upstream supply chain data collection to improve the specificity of the LCA and its results, and maximizes the utility of LCAs and EPDs as tools for decision making.

The development of a software tool that programs PCR guidelines directly into the LCA tool and expedites the creation of consistent EPDs could be of great benefit. Early successes have been demonstrated by the concrete (multiple tools and examples) and asphalt industries.

Ultimately, PCRs should be the guardrails for what and how much information goes into LCAs and EPDs. Quality PCRs will help ensure that results can reliably inform users seeking EPDs for the current carbon accounting for the various use cases.

American Chemistry Council

The Embodied and Operational Carbon Data Ecosystem in 2023

Most of our assumptions around the contribution of buildings to GHG emissions are based on data from 2006-2008 (see timeline below). This data is outdated and likely does not accurately represent our current GHG emissions allocations.

2006 — **IPCC Guidelines for National Greenhouse Gas Inventories**

2007 — **IPCC Fourth Assessment Report (AR4)**

2008 — **International Standard Industrial Classification of All Economic Activities (ISIC, Rev. 4)**

2021 — **IEA World Energy Balances**; **IEA Greenhouse Gas Emissions from Energy**

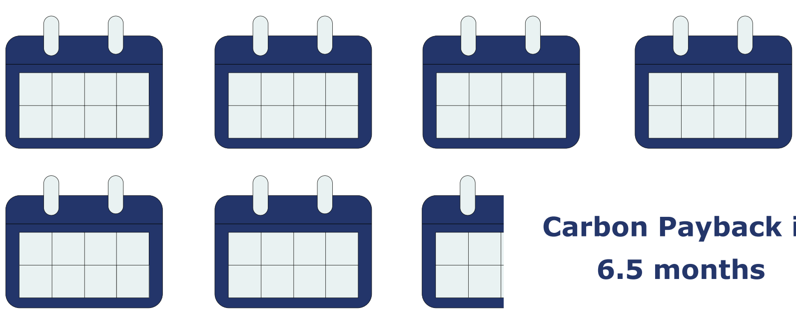
2022 — **Global Status Report for Buildings and Construction**

with reference to

with reference to

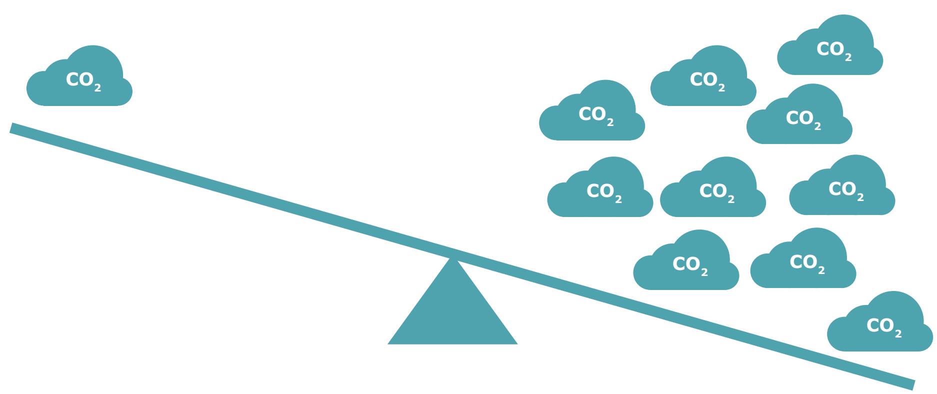
In most cases, an embodied carbon insulation investment will pay itself back quickly, often in less than one year of operations.

For example, commercial Wall Insulation impact has full Carbon Payback in 6.5 months in cold climates (Climate Zone 5) in Medium Renewable Energy (RE) Cost markets.[1]



Carbon Payback in 6.5 months

The carbon avoidance ratio shows that under certain conditions, for every unit of embodied carbon invested in the building, you could save up to 251 times the carbon during the 75-year life of the building.[2]



[1] Determination of Total Carbon Impact of Plastic Insulation Materials, ICF, August 29, 2023. https://www.americanchemistry.com/better-policy-regulation/plastics/resources/determination-of-total-carbon-impact-of-plastic-insulation-materials

[2] Assuming the current mix of heating system technologies, CZ5 installation and Medium RE Cost, Wall Insulation saves 251x its embodied carbon impact. The functional unit is kilograms (kg) of CO2eq/m2 of insulation based on an RSI value of 1 based on a 75-year service life.

The Embodied and Operational Carbon Data Ecosystem in 2023

Goal

A full life cycle approach can support efficient design selection that optimizes operational emissions, while reducing embodied emissions of materials.

The goal is to reduce overall carbon emissions by understanding the intersection of embodied and operational emissions.

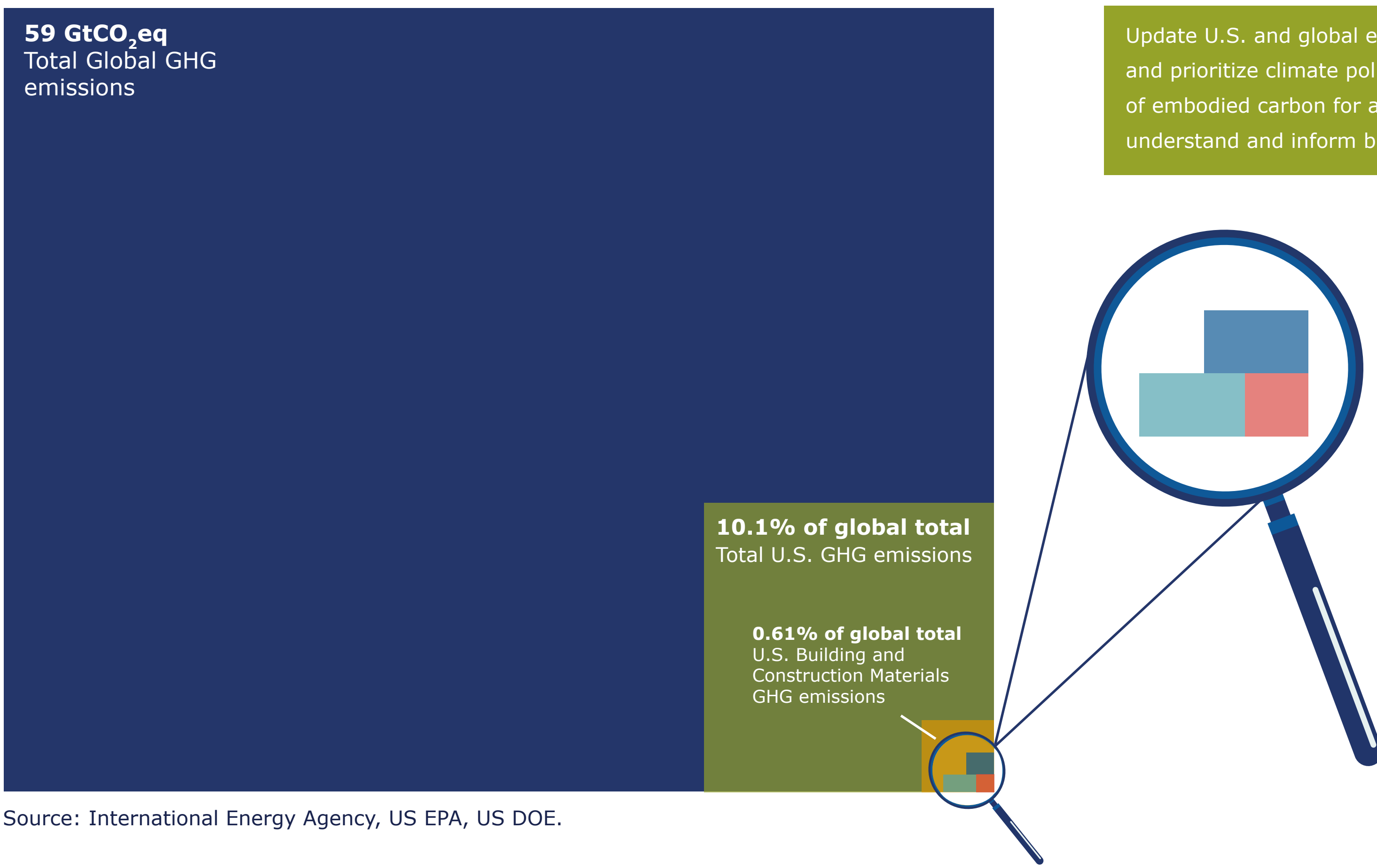
Opportunity

Technologies like insulation enable efficiencies in electrification that help us further on the path of decarbonization.

Challenge

There are only a small percentage of building materials that currently have embodied carbon data. In addition, embodied carbon and operational carbon are often not considered together, which results in a large gap in understanding the overall carbon impacts of procurement decisions.

Global and U.S. Allocation of Emissions from Energy



Source: International Energy Agency, US EPA, US DOE.

Action Item

Update U.S. and global emissions data to better understand and prioritize climate policies and document the breakdown of embodied carbon for additional buildling materials to better understand and inform building design.

Building insulation = 0.10% of total US GHG emissions

Structural steel = 0.9% of total US GHG emissions

Concrete = 1.7% of total US GHG emissions

Whole Building Life Cycle Assessment Tools

This paper was developed by WAP Sustainability with the support of the American Chemistry Council. It is not intended and should not be interpreted to endorse or disfavor any particular tool or tools but aims to provide users and product manufacturers useful information regarding the tools as they pertain to specific project needs.

In building and construction, greenhouse gas (GHG) emissions (or "carbon impacts") are often differentiated into two categories: operational carbon (OC) (attributed to operational energy consumption during the building's lifetime) and embodied carbon (EC). Embodied carbon of building materials includes estimated GHG emissions associated with material extraction, manufacturing and transportation, construction, maintenance, replacement/repair, demolition/deconstruction, and disposal). Addressing both OC and EC categories through a "total" or "whole life" carbon approach enables a more comprehensive strategy to reducing emissions throughout the whole lifecycle of a building.

Whole building life cycle assessment (WBLCA) is one of the most comprehensive ways to communicate total carbon impacts of buildings and building materials. WBLCA tools compile data to estimate the environmental impacts of a building throughout its useful life, including its Global Warming Potential (GWP). The results of a WBLCA inform strategies to reduce carbon impacts of the building during its lifetime.

Various tools are available for WBLCAs. These tools range in maturity, sophistication, and accuracy. The WBLCA Tools table provides information on some of these tools' capabilities and limitations that readers can evaluate as they determine which tools best address their own needs and circumstances. Due to space limitations, the table does not include all available tools but provides information on those commonly used. Users are encouraged to evaluate additional informational sources to support informed, independent decision-making. While the presented information is believed to be accurate, no warranties are provided.

Data Quality

The data quality supporting each of these tools is varied. It is affected by multiple factors, such as:

- quality and consistency of life cycle inventory (LCI) data;
- EPD database inconsistencies;
- EPD availability;
- manual input and data transmission errors;
- tool multipliers;
- the inclusion of products data derived from various PCRs and different versions of PCRs;
- differences in background data processing;
- etc.

Additionally, at this time there are few capabilities in these tools to assess and communicate the quality of data sources or provide any indication to users of unreasonable assumptions or uncertainty in the data. This is sometimes partially indicated in the tool documentation, but is generally not emphasized within the tool or user interface. This can lead to compounding errors that are not transparent in the results supplied to tool users and factored into design and procurement processes.

For example, the main sources of life cycle inventory (LCI) data are two databases: GaBi and Ecoinvent. Both datasets offer different and competing levels of quality. LCI data feeds WBLCA evaluations and tool functionality. Industries also often fund LCI development to ensure WBLCA tools are appropriately characterizing the environmental impacts of their products. For now, software tools will use different data sources, variables and assumptions to support modeling based on their individual value proposition to their customers, which creates inconsistencies in results and interpretation.

A study comparing Tally and Athena's assessment results on the same building assembly revealed up to a 42% variance between their calculated global warming potential. In addition, material or assembly data is often very broad and averaged in modeling tools that do not pull product specific LCA or EPD data from a database. Even with specific data, often the underlying assumptions and data transformations, when factored into assembly or building models, are difficult to view and understand. Quality check capabilities are limited and mostly assess integrity of the building model and not quality of LCA data.

In some cases, WBLCA models omit entire categories of materials, such as mechanical, electrical, and plumbing (MEP) equipment, due to lack of reliable LCI data. If it is modeled, the data is very generalized and contributes to issues with using generalized data. Manufacturers in EC-emerging industries are quickly collaborating on rules and best practices for adding their products to WBLCA tools.

It is important for users to understand the limitations of data generation and modeling in the context of making building and material decisions. There is ongoing work throughout the entire process from LCI data consistency to collaboration within industries and updates to WBLCA software improvements to ensure that reliable data is being used to make good decisions. Further, the increasing number of product specific EPDs being developed by manufacturers will likely decrease overall dependency on background LCI data in the future.

Carbon Impact Tool Descriptions

Athena Impact Estimator for Buildings

https://calculatelca.com/software/impact-estimator/

The Athena Impact Estimator for Buildings (Athena IE) evaluates whole or partial buildings from an input of building assemblies or a bill of materials. Athena IE primarily functions as a text-based LCA tool where users describe building assemblies through dialogue boxes that request simple information like bay sizes and loads. The software calculates a bill of materials and the associated environmental impacts. Thus, users select and add elements to represent the building as closely as possible.

Users can also import their own bill of materials from any CAD program, as an alternative to manual input.

Athena IE can be used in any design stage.

Athena IE data is regionally customized within North America and drawn from the proprietary Athena Life Cycle Inventory (LCI) database, the US LCI database, and Ecoinvent. Environmental Product Declarations (EPDs) cannot be accessed from the tool. Transportation, localization, and service life values per material cannot be modified.

Athena IE does not include an operational energy modeling capability, but it does allow users to enter separate energy modeling data to compute total carbon impacts. It also does not have a way to QC the process or results.

The software was updated in 2020, and a new version is expected in 2023.

Buildings and Habitats object Model (BHoM) Life Cycle Assessment Toolkit

https://bhom.xyz/

Buro Happold's BHoM is an open-source model supported by architects, engineers, and software developers that provides a single common language to facilitate data transfer between design and engineering software tools. Instead of creating individual translators between every piece of software, the BHoM serves as the intermediate translator, or central model, between all compatible software. In this way, the BHoM is used to relate data between tools that are normally incompatible or would require a difficult data transfer or significant manual data input.

As an example of the tool's capability, users can pull building information modeling (BIM) data and objects from Revit into Grasshopper, Dynamo or Excel, apply EPD data sets to those objects, and evaluate embodied carbon impacts before pushing the data back to Revit or to other visualization engines for additional analysis. The toolkit also supports direct import of material quantities. BHoM connects material quantities to LCA and EPD data from multiple open-source databases including EC3, Quartz, ICE, etc.

BHoM facilitates interoperability and enhances data and models in other WBLCA tools but is not a standalone tool that is capable of producing a WBLCA on its own. The network of contributors aims to enhance workflows between WBLCA tools and improve their effectiveness in handling increasing informational complexity and volume, which will be important for the increase in EPD development and digitization of EPD data.

cove.tool

https://www.cove.tools/embodied-carbon-feature

cove.tool is a web- and plugin-based suite of tools that focuses on early-stage design phases that require rapid, iterative feedback. Its integrated tools support rapid 3D modeling and prototyping (drawing.tool), energy and daylighting modeling (analysis.tool), HVAC sizing and modeling (loadmodeling.tool), and a lead generator that connects manufacturers and project teams throughout the modeling process (revgen.tool). It does not conduct whole building life cycle assessment or quantify carbon impacts of the building design.

There are some ways to partially understand carbon impacts through cove.tool. It has a cost versus energy optimization feature that runs whole building simulations of multiple material selection options and identifies the optimal combination of material variables based on cost and energy parameters. Embodied carbon is an optional and manual input. Users click through to the Embodied Carbon in Construction Calculator (EC3) and copy and paste the appropriate value, but the value is not factored into the building model's energy optimization determinations.

At the material assembly level, the Assembly Builder feature calculates performance, cost and carbon values for material assemblies based on the EC3 embodied carbon baseline for the component product category. Embodied carbon intensity (kg CO_2-eq per unit area) is pre-populated based on the materials selected for the assembly with no indication of how it was calculated or the source data, though the default values and assumptions can be manually updated. An enhanced Embodied Carbon Feature has been announced but no release date has been published.

Early Phase Integrated Carbon (EPIC) Assessment

https://epic.ehdd.com/
https://epic-documentation.gitbook.io/epic/

The EPIC Assessment tool was created to overcome the scarcity of data in early design phases that could inform embodied carbon reductions and assess potential impacts of embodied carbon. EPIC's model includes U.S. regionally-specific data, forward-looking projections, and built-in assumptions (base case energy use intensity (EUI), percentage of onsite fossil fuel combustion, rough building dimensions, and interior fit-out percentage). It allows a user to edit specific project parameters and baseline assumptions to test the effects of carbon reduction strategies for their specific project.

The model scope includes building structure: cladding, glazing, and roofing (and replacement of cladding and glazing); interior fit-out (and replacement of interior fit-out); mechanical, electrical and plumbing (MEP) systems; photovoltaic arrays; and annual landscape maintenance. Material carbon intensity data is taken from other tools and peer-reviewed publications, and are either national averages or product/assembly type averages.

For operational carbon, EPIC includes the emissions based on state-specific grid averages. Onsite fossil fuel use is assumed to be natural gas, and its contribution to total energy use is based on averages from the Commercial Buildings Energy Consumption Survey (CBECS) and Residential Energy and Consumption Survey (RECS) databases. The model can account for biogenic/stored carbon from timber-based structural materials and site landscaping. The tool has an appendix that documents relevant assumptions and the calculation methodology. The beta version of the tool was released in June 2022, and two minor updates to fix software bugs have been released since then.

Embodied Carbon in Construction Calculator (EC3)

https://www.buildingtransparency.org/

EC3 focuses on the cradle-to-gate emissions of construction materials and sets targets for procurement decisions. Users manually enter material quantity data to model their construction estimates or bill of materials.
A Revit plugin is under development. EC3 contains a database of digitized Environmental Product Declarations (EPDs), which can facilitate a visual and technological comparison of key product attributes extracted from static documents for products in the same product category. The tool does not police data inputs.

EC3 is most often used as an EPD comparison tool. Select product categories and associated product EPDs are currently available in the EC3 database. Both product-specific and industry-wide data are included. Users often review product specific EPDs against the Carbon Leadership Forum (CLF) Baseline to determine whether that specific product helps meet their project goals. Rather than take a mathematical average and to account for uncertainty in data, the CLF Baseline marker corresponds to the threshold where 20% of products exceed the desired embodied carbon intensity. Error bars are provided to show that there is some room for error in data comparisons. The most recent material baselines can be found in CLF's 2021 Material Baseline Report.

One Click LCA and Carbon Designer 3D

https://www.oneclicklca.com/
https://www.oneclicklca.com/carbon-designer-3d/

One Click LCA is a fully automated web-based, text-input software tool that also has a Revit plug-in. It takes data from sources such as Revit and other BIM models, costing spreadsheets, or energy models and combines the data into a WBLCA. The software meets requirements for over 40 green building certification programs. Carbon Designer 3D is an add-on early phase tool that estimates a building's carbon footprint based on size and type of building. The tool comes with ready-to-use localized reference buildings and allows users to create their own scenarios. Carbon hotspots are visualized in heatmaps of 3D structure models that allow designers to explain carbon intensity to other designers and project owners.

One Click LCA integrates data from EPD platforms to develop its own construction materials database.
EPD data is presented as it pertains to the project's specific geography and target certifications. All data in the One Click LCA database undergoes a ten-point verification using a process that has been reviewed by the Building Research Establishment (BRE). Some EPDs may be deemed to have ineligible results. They can still be added to the database but are not automatically integrated into the software. A warning is displayed for such EPDs. If the error is only minor, a user can manually confirm that they want to use the EPD. The tool also allows users to directly add additional or alternative materials and adjust numerical inputs to compare two or more buildings scenarios. The LCA Checker function informs users if materials are missing or if quantities are reasonable based on project type and size.

tallyLCA (Tally) and tallyCAT (Tally Climate Action Tool)

https://choosetally.com/
https://www.buildingtransparency.org/tally/tallycat/

Tally is a Revit plugin that allows users to determine relationships between BIM elements and information on construction materials from the Tally database. Tally quantifies a building's or material's embodied environmental impacts to land, air, and water systems. Essentially, Tally adds another layer of detail to BIM by recognizing materials that are not modeled explicitly, such as the steel in concrete assemblies. Tally was initially developed to translate mass-based life cycle impacts into the design process and embed embodied carbon information into a building model to understand how material type and weight impact a building's total carbon. Tally utilizes a custom-designed database that combines material attributes, assembly details, and architectural specifications with environmental impact data with little indication of source data and pre-populated assumptions and calculations. The data is specific to the United States. Tally does not have an ability to assess the quality of results.

Building Transparency's new tool, the Tally Climate Action Tool (tallyCAT), provides real-time synchronization of EPD data between EC3 and Revit. This allows designers to identify carbon reduction opportunities in the Revit environment. This addresses a lack of interoperability between LCA tools and BIM-based analysis methods of building design.

Collaborators including Building Transparency, Perkins & Will and C-Change Labs plan to make tallyCAT a whole-life carbon tool and plan to release an updated version in 2023. Both tallyLCA and tallyCAT are on track to become free and open-access tools.

WBLCA Tools

	Athena IE	BHoM	cove.tool	EC3	EPIC	One Click LCA	Tally
Design Stage Applicability SD = Schematic Design DD = Design Development	SD, DD	DD	SD, DD	SD, DD, Procure-ment	Pre-design	Pre-design, Early SD, and DD	SD, DD
Cost	Free	Free	Custom pricing	Free	Free	Custom pricing	Set license fee
General Attributes							
Ability to QC data and results easily	No	No	No	Partial	No	Partial	No
Ability to sync LCA with geometry updates	No	Yes	Yes	Partial	No	Partial	Yes
Utilizes or links to open-source data	No	Yes	No	No	Yes	Yes	No
Wide variety of building material types*	Yes	Partial	Partial	No	Yes	Yes	Yes
Transparency of underlying carbon intensity assumptions (access to kgCO2e/kg value)	No	Yes	Unknown	Yes	No	Partial	No
Data Quality and Specificity							
Data quality	Partial	Partial	Partial	Partial	No	Partial	Partial
Populated with assumptions for US context (or US data is a subset of globally comprehensive database)	Yes	Varies	Yes	Yes	Yes	Partial	Yes
Are data updated regularly?	Yes	Yes	Yes	Partial	Yes	Yes	Yes
Life Cycle Stages							
A1-A3	Yes	Yes	Yes	No	Partial	Yes	Yes
A4-A5	Yes	Varies	No	No	Partial	Yes	Partial
B1-B4	Yes	Varies	No	No	Partial	Yes	Partial
B6-B7	Yes	Varies	Yes	No	Partial	Yes	Yes
C1-C3	Yes	Varies	No	No	Partial	Yes	Yes
Module D (Reuse, Recycling, Energy Recovery)	No	Varies	No	No	Partial	Yes	Yes
Can include biogenic carbon accounting	Partial	Varies	No	Varies	Partial	Yes	Yes
Customization of Data							
Ability to input energy of construction	Unknown	No	No	No	No	Yes	Yes
Ability to edit transportation distances	No	No	No	No	No	Yes	Yes
Ability to edit operational energy and water usage	No	No	Yes	No	Partial	Unknown	Yes
Ability to input specific LCA or data without developer assistance	No	Yes	Yes	No	No	No	No
Output and Results							
Ability to QC output**	No	Yes	Yes	Partial	No	Yes	Yes
Export to multiple tools (e.g. Excel, Revit, Rhino…)	No	Yes	Partial	No	No	Yes	Yes
Can break out lifecycle impact by material category (e.g. structure, wall assembly, flooring)	Yes	Yes	No	Yes	Partial	Yes	Yes
Can break out lifecycle impact by material type (e.g. steel rebar, PVC flooring)	Yes	Yes	No	Yes	Partial	Yes	Yes
Can break out lifecycle impact by life cycle stage	Yes	Unknown	No	Unknown	Partial	Yes	Yes

* This criterion assesses how many different product categories' data are integrated into the tool. Product categories available within a tool vary significantly. For example, EC3 has worked with industry associations to integrate select product category types, focusing on common interpretation of data rather than quantity of data. Other tools like OneClick LCA connect to as many EPD databases as possible but do less critical work to resolve discrepancies in data quality prior to integration.

** The ability to quality check the output of the tool typically assesses the integrity and completeness of modelling the building and its required components. For example, it may check structural systems and assemblies for expected components. It will usually not evaluate assumptions, data sources or data quality of the input LCI, LCA or EPD data.

Key

- **Yes**
- **No**
- **Partial.** Some tool aspects address the criterion.
- **Varies.** Tool addresses the criterion but requires the user to know how to manipulate the data or model to fulfill that function.
- **Unknown.** Not enough information to conclude how the criterion was ad-dressed, or desired outcomes are more user- and less software-dependent.