EMBODIED CARBON in CONSTRUCTION CALCULATOR

EMBODIED CARBON IN THE EC3 TOOL: BETA METHODOLOGY REPORT

http://carbonleadershipforum.org/projects/ec3/

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To participate in the work to test and refine these methods and be invited to technical discussions, please send a request to CLFdataEC3@uw.edu. We are actively looking for help to refine and improve these methods and to improve the quality, quantity and accessibility of embodied carbon data available. Please let us know if you have data and/or methods that you can share for inclusion into the methodology or database.

Disclosure
Content produced in this document does not necessarily represent the perspective of contributors, advisory committee members, technical experts or sponsors of the Carbon Leadership Forum or the EC3 tool. The following organizations have sponsored this project with the University of Washington's Carbon Leadership Forum: Autodesk, the Charles Pankow Foundation, Interface, Magnusson Klemencic Associates, Microsoft, Skanska, Alexandria, BASF, Perkin & Will, Port of Seattle, Tally, Walter P Moore, Webcor, and others totaling nearly 50 partners. Additional support is provided by Carbon Leadership Forum Sponsors who include Magnusson Klemencic Associates, Mithun, StopWaste, Carbon Innovations, the Russell Family Foundation, the American Institute of Architects, Arup, Carbon Cure, Central Concrete, Interface, Kieran Timberlake, Orca, Sellen, Skanska, Thornton Tomasetti, WAP Sustainability Consulting, and WeWork. Twenty-four additional supporters provide funding at lower levels. Current sponsors are identified at www.carbonleadershipforum.org.

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November 19, 2019

Executive Summary

The Embodied Carbon in Construction Calculator (EC3) tool is a free open access tool that allows benchmarking, assessment and reductions in embodied carbon, focused on the upfront supply chain emissions of construction materials. The EC3 tool utilizes building material quantities from construction estimates and/or BIM models and a database of digital, third-party verified Environmental Product Declarations (EPDs). Powered by this data, the EC3 tool can be implemented in both the design and procurement phases of a construction project to look at a project's overall embodied carbon emissions, enabling the specification and procurement of low carbon options. The EC3 tool has been incubated at the Carbon Leadership Forum in collaboration with C Change Labs and developed with input from nearly 50 industry partners. The Carbon Leadership Forum is responsible for developing the methods to categorize data and assess EPDs that are used in the EC3 tool.

This report is an update of documentation presented in Summer 2019 for stakeholder input and represents the core data methodology as implemented into the EC3 tool at the time of Beta launch in November 2019. In addition to this core document, material specific reports are in development. We are actively looking for help to refine these methods and look forward to helping to accelerate the standardization of calculation and reporting of uncertainty and variability in EPDs. If you are interested in engaging in the technical committees supporting the methodology development, please email CLFdataEC3@uw.edu to gain access to draft material reports and invitations to calls that provide updates and forums for discussion.

- **Note: items in red highlight issues specific to the functionality of the tool at Beta launch.**
  Sections 1-3 provide a more general overview of the tool-A good introduction.
  Section 4 goes into more technical detail-More geared towards data/LCA expertise.

Contents

1 Embodied carbon overview

Globally, the building and construction sectors account for nearly 40% of global energy-related carbon dioxide emissions (including the impacts of upstream power generation).[1] Current building codes address operating energy, but do not typically address the impacts 'embodied' in building materials and products. However, more than half of all GHG emissions are related to materials management (including material extraction and manufacturing) when aggregated across industrial sectors.[2] As building operations become more efficient, these embodied impacts related to producing building materials become increasingly significant.

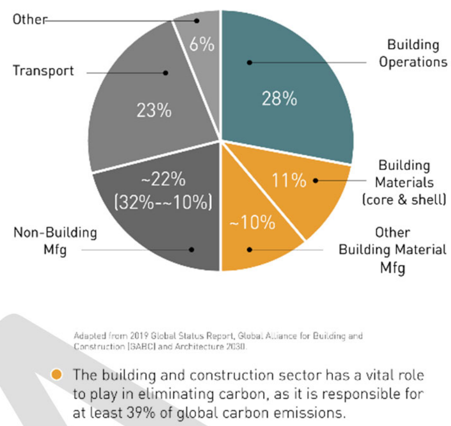


Figure 1. Global CO_2 emissions by sector.

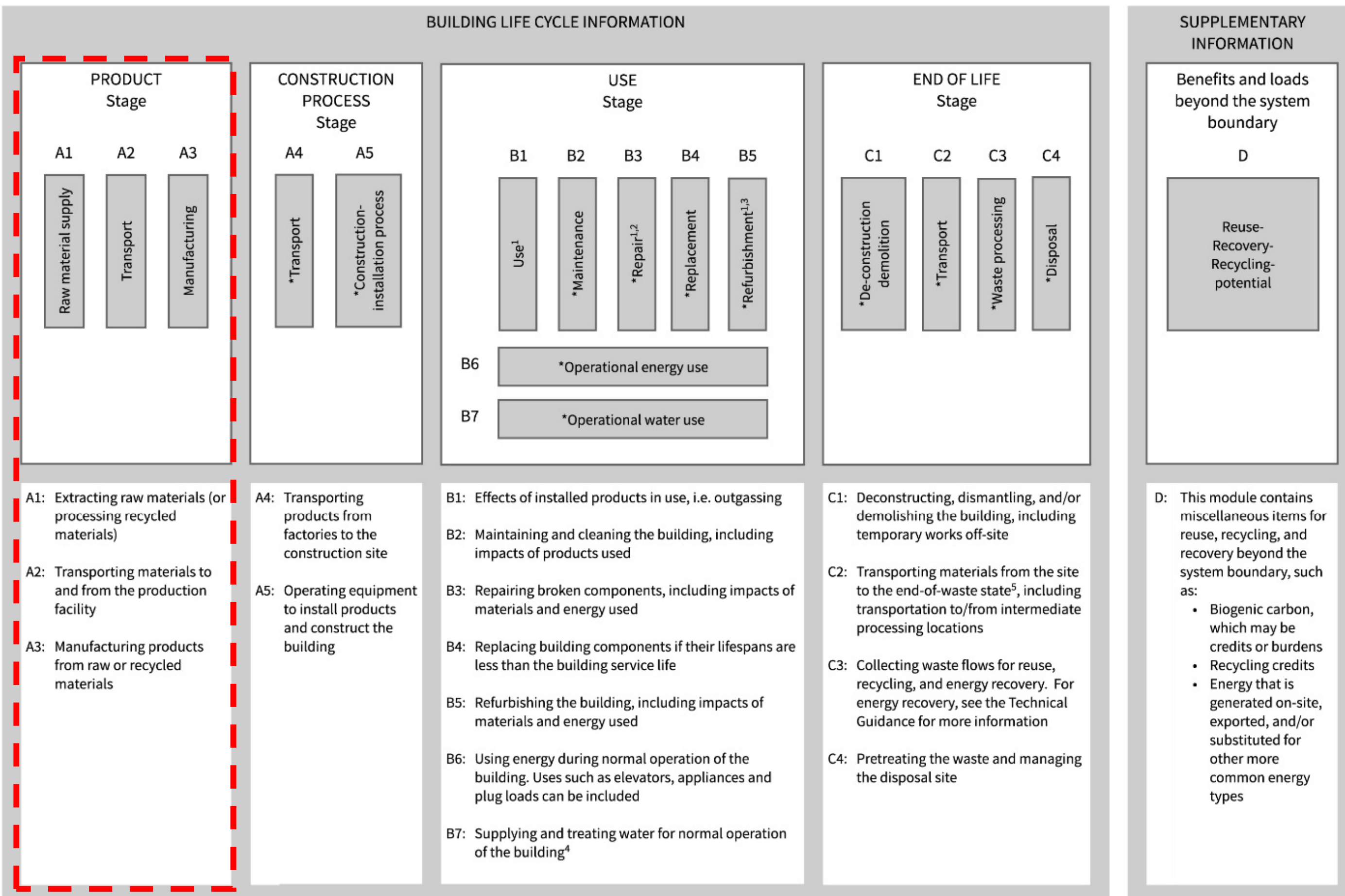
In order to understand the magnitude of emissions produced by materials manufacturing, an accounting of emissions along the supply chain is required. Life cycle assessment (LCA) is a standardized environmental accounting method that can track these emissions, beginning with raw materials extracted from nature through manufacturing, use of materials, and end-of-life processes. LCA reports a range of potential environmental impacts of these emissions, including GHG emissions reported as a standard metric termed global warming potential (GWP), which is expressed in kilograms of carbon dioxide equivalent (kg CO_2e). GHG emissions arising from material extraction and product manufacturing is commonly referred to as *embodied carbon*, which is the focus of this project. Reducing the embodied carbon of products can have significant regional and global impacts.

Figure 2. Carbon emissions in building: 'upfront' embodied carbon and operational carbon.

[1] UNEP and IEA, "Global Status Report 2017: Towards a Zero-Emission, Efficient, and Resilient Buildings and Construction Sector," 2017.

[2] OECD, "Global Material Resources Outlook to 2060: Economic Drivers and Environmental Consequences" (Paris, 2019), https://doi.org/https://doi.org/10.1787/9789264307452-en.

LCA standards and project category rules (PCRs) divide the impacts that occur over the life cycle of a product according to the modules shown in Figure 3. Modules A1-A3 cover the product manufacturing stage from raw material extraction to manufacturing, and are often characterized as 'cradle-to-gate,' or from beginning-of-life to the factory gate. This cradle-to-gate scope comprises the majority of impacts 'embodied' in 'embodied carbon' for the majority of materials. Additional impacts from transportation and installation (A4-A5) can also be considered in 'upfront' embodied carbon but are not included in the EC3 tool at this time.



* Scenario descriptions required
[1] These modules are currently not well-supported by LCA databases and tools.
[2] Repair is defined as "returning an item to an acceptable condition by the renewal, replacement or mending of worn, damaged or degraded parts" [9].
[3] Refurbishment is defined as "modification and improvements to an existing building in order to bring it up to an acceptable condition" [9].
[4] Note that tracking operational water use is not common in whole building LCA tools and requires further development of the methodology.
[5] EN 15978 defines the end-of-waste state in Section 7.4.5.4.

Figure 3. LCA stages and modules per EN 15978, reproduced from *Life Cycle Assessment of Buildings: A Practice Guide.* Dashed line highlights the focus of the EC3 tool.[3]

Note that whole building LCA and embodied carbon reduction strategies, such as those covered in stages A4 through D, are not the focus of the EC3 tool. The EC3 tool should be used to supplement and improve whole building LCA modeling. It should not be seen as a replacement for whole building LCA.

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[3] Carbon Leadership Forum, "Life Cycle Assessment of Buildings: A Practice Guide," 2018, https://doi.org/http://hdl.handle.net/1773/41885.

1.1 Environmental product declarations (EPDs)

EPDs are summaries of LCA reports that may be third-party verified and follow a standardized accounting method (ISO 21930, EN15804 or others) outlined in a designated PCR, and are hosted by an EPD program operator. Program operators are organizations (independent companies, non-governmental organizations, or trade organizations) that oversee the third-party review of EPDs, as required by ISO EPD standards. There are multiple program operators in North America. Each program operator is responsible for publishing EPDs in a public manner. While each program operator maintains its own EPD database, there are several databases that aggregate EPDs from multiple program operators.

Since 2016, a catalog of all North America PCRs for building products, organized by MasterFormat® division, has been maintained by Sustainable Minds. In January 2019, Sustainable Minds added all available North American EPDs to its Transparency Catalog. [4] Additional materials databases such as ULeSPOT and mindful MATERIALS include EPDs. None of these extract data from the EPDs (rather, they host documents) and thus cannot not be used to sort materials based on LCA results such as embodied carbon.

Different materials and products report data at different levels of detail, which can make it difficult to compare EPDs because they have different underlying assumptions. The comparability of EPDs (or lack thereof) is important to consider when comparing the environmental impacts of products. Factors that impact the comparability of embodied carbon reported in EPDs include:

1. *Methodology:* Do EPDs follow the same PCR? The PCR author and version can have a significant impact on the methods used to calculate LCA impacts.
2. *Upstream data:* Do EPDs use aligned upstream data for significant impacts such as electrical generation or transportation? Is upstream data current? If upstream data (life cycle inventory datasets) are not aligned, variation in results can be significant especially in impact categories other than GHG emissions.
3. *Performance:* Do the compared materials have the same performance characteristics? Two products of the same material category may have significantly different performance characteristics (e.g. 3,000 psi concrete for a foundation vs 5,000 psi concrete for a high-rise floor slab), which would make it inappropriate to compare their EPDs.
4. *Installation, use, and end-of-life:* If all life cycle stages after manufacturing are not identical, comparing embodied carbon alone is not appropriate and LCA data should be considered in the context of a 'whole-building' LCA instead of an EPD comparison

There are different types of LCA data available, affecting how embodied carbon estimates are assessed in this review. Standards for assessing life cycle inventory (LCI) data (the foundational data behind LCAs) can be applied to this project. ISO standards[5] outline ten categories that should be addressed including issues of the time, region, technology as well as other data quality metrics.

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[4] Program Operator Consortium, "North American PCR Catalog (Google Sheet)," accessed December 14, 2018, https://docs.google.com/spreadsheets/u/1/d/1lS7ukMUG1cAWnMGHKiqIvgcgeHQOeICIIH5t95InZy8/pubhtml.

[5] ISO, "ISO 14044: Environmental Management -- Life Cycle Assessment -- Requirements and Guidelines," *ISO* (International Organization for Standardization, 2006), https://doi.org/10.5594/J09750.

Different types of EPDs and LCA data exist for materials and products as outlined below.

1. *Industry-average EPD:* Results are weighted to reflect production methods and regional output for a product. Sometimes only a sample of companies participate in the creation of the EPD and thus the EPD may not be truly representative of the average in the industry.
2. *Facility-specific EPD:* Results represent production of a specific product at a unique facility.
3. *Product-specific or manufacturer-specific EPD:* Results are representative of the processes for a specific product or family of products made by a unique manufacturer. This may be a weighted average of different production facilities.
4. *Publicized LCA studies,* with and without third party review.
5. *Private LCA datasets,* with and without third party review

The dominant standard for creation of EPDs is ISO 21930, which was significantly updated in 2017. European PCRs typically comply with EN 15804. While updates of the material PCRs are in different levels of development, only select EPDs are currently following the 2017 version of ISO 21930 as of time of writing as most PCRs are just now expiring after their first five-year term. Key changes in the new version of the standard include: increased clarity regarding reporting the carbon emitted in burning bio-fuels/bio-mass, and the more detail regarding reporting of variability and uncertainty.

1.2 Discussion

Given that materials within the same material category commonly have similar construction, use, and end-of-life impacts, comparing cradle-to-gate EPDs can be appropriate within a material category (e.g. steel 'A' vs steel 'B'). Given that the installation, use, and end-of-life impacts vary by material, comparing cradle-to-gate EPDs of different material category (e.g. steel vs wood, or even precast concrete vs ready-mix concrete) is not appropriate without conducting a more detailed LCA. The intent of analysis for the EC3 tool is thus to evaluate options for differentiating products of the same material category, e.g. selecting the 'cleanest' structural steel available. The purpose of the tool is not to compare different material categories, such as steel versus concrete, and thus does not answer questions such as, "Is a steel or concrete structure a lower-emission option for a building?". The EC3 tool points users to whole building LCA tools to answer questions such as this.

Note that EPD results for one product can be the LCA impact for stage A1 of another product. For example, modules A1-A3 of cement production is included in module A1 of concrete because cement is an ingredient of concrete. A 'facility-specific' EPD typically refers to the facility responsible for the last stage of manufacturing (module A3) of the product. However, for some materials, the largest impacts and largest variability of impacts occur 'upstream' and are reported in LCA stage A1. For some material categories, the most significant contributor to embodied carbon will be not the facility that fabricates the material but rather the facility/facilities that produce(s) the upstream materials. Thus, in some instances in order for an EPD to be representative of actual emissions, facility specific data for key upstream processes needs to be included in the LCA. Ideally EPDs would include supply chain specific LCA data for the majority of the contributions to each life cycle stage.

2 Materials in the EC3 tool

The EC3 tool aims to be a comprehensive resource for building material embodied carbon estimates. The categories selected for the public Beta launch of EC3 tool were selected to capture primary structure, enclosure and finish materials used in commercial construction and developed in as much detail as the project funding permitted. Current materials include:

1. *Structure:* Concrete, Steel, Wood
2. *Enclosure:* Aluminum, Glass, Insulation
3. *Finishes:* Carpet, Ceiling tiles, Gypsum wall board

Note that for any of these materials, additional components such as concrete formwork, reinforcing ties, fasteners and other materials and components are required to create a full building assembly. The EC3 tool currently focuses only on the primary materials of the elements noted above.

Examples of impact sources and their approximate percentage contributions for common structural materials by life cycle module is shown in Table 1. Material reports will describe impacts in greater detail for each material.

Table 1. Summary of LCA impacts per LCA module and relative impact for common structural materials.

Material category	Property	A1	A2	A3
Structural steel[6]	Approx. % of impact:	>90%	<5%	<10%
	Source of impacts:	Ore mining, steelmaking	Transportation to fabricator	Cutting, welding, shaping steel
Concrete[7]	Approx. % of impact:	>80%	<20%	<10%
	Source of impacts:	Production of cement, aggregate, and admixtures	Transportation to concrete plant	Mix design and concrete mixing
Cement[8]	Approx. % of impact:	<10%	<5%	>90%
	Source of impacts:	Raw material mining	Transportation to cement kiln	Manufacturing cement
Clay masonry[9]	Approx. % of impact:	<5%	small	>95%
	Source of impacts:	Mining of clay	Transportation and storage	Firing and factory operations
Glue laminated beam[10]	Approx. % of impact*	<10%	<5%	>90%
	Source of impacts:	Lumber planting, harvest, drying and milling	Transportation to a fabricator	Drying, cutting, gluing, pressing

*not including emissions from bio-fuel combustion or emissions within the broader forest context.

The environmental impact of local fabrication or assembly can be quite small compared to the environmental impact of the upstream material manufacturing. Therefore, even though few local companies currently have facility-specific EPDs for their products, this part of the supply chain is not

[6] Ule, "Environmental Product Declaration Fabricateed Hot-Rolled Structural Sections," 2016.
[7] NSF, "NRMCA Member Industry-Wide EPD for Ready Mixed Concrete," 2016.
[8] Portland Cement Association and ASTM International, "Portland Cements Environmental Product Declaration," 2016, https://www.astm.org/CERTIFICATION/DOCS/295.EPD_for_Portland_Cements_-_Industry_Wide_EPD.pdf.
[9] Christophe Rafenberg and Eric Mayer, "Life Cycle Analysis of the Newspaper Le MONDE," *International Journal of Life Cycle Assessment*, 1998, https://calculatelca.com/wp-content/themes/athenasmisoftware/images/LCA Reports/Brick_And_Mortar_Products.pdf.
[10] Ule, "Environmental Product Declaration North American Glued Laminated Timbers," 2013.

always a major environmental concern. Instead, it may be more important to focus on gathering accurate (or regionally-specific) data for the upstream parts of the supply chain.

3 Evaluating and reporting data in the EC3 tool

Within the EC3 tool, two key actions are taken: estimating uncertainty **[Beta version: simply and consistently applied across all product categories to help demonstrate and get stakeholder feedback]** and using the 'burden of the doubt' approach to evaluate embodied carbon results.

3.1 Applying the burden of the doubt approach

Current LCA practice defaults to industry average data for upstream materials. This 'benefit of the doubt' method is not conservative as it presumes materials will be 'average' or better. Given that ISO 21970:2017:7.1.8 states 'data gaps shall be filled with conservative assumptions' and that using industry average data for highly variable processes is not conservative, alternative methods should be explored.

Rather than taking the 'benefit of the doubt', a 'burden of the doubt' approach is taken. If an EPD is uncertain, the degree of uncertainty is estimated and the EPD is evaluated based on a conservative estimate – the 'high' range of the estimate rather than the average. The EC3 tool represents the range of materials in a specific category by the green box and whisker plot on the left side of Figure 4. The results reported in the EPD is indicated by the black bounded by a light blue band representing the estimated uncertainty/variability in the EPD. While all uncertainties are approximated in the EC3 tool at this time, the ultimate goal is that this data is reported within the EPDs and when this occurs, the EPD results will take precedence over estimated uncertainty.

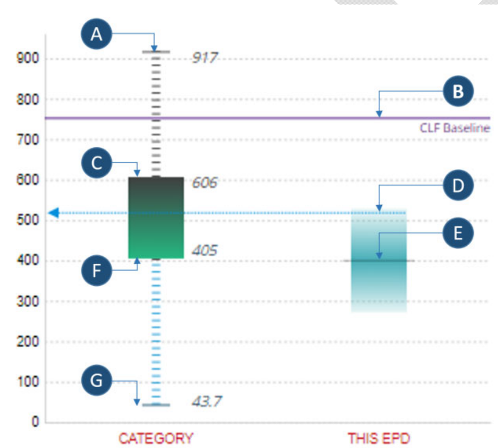


Figure 4. Visualizing the burden of the doubt approach.

Interpreting data visualization in the EC3 tool

A. Highest results for this category in the database
B. CLF Beta Baseline – high estimate per category
C. GWP of 80% of EPDs in category is below this
D. EPD result plus uncertainty estimate – EC3 value
E. EPD embodied carbon result
F. GWP of 20% of EPDs in category is below this
G. Lowest results for this category in the database

A primary goal of the EC3 tool is to help users interpret EPDs via two primary functions:

1. Grouping EPDs based on performance, and
2. Estimating the variability (range of reasonably expected results) and uncertainty (precision of LCA data) within EPDs when this data is not provided within the EPD.

The following sections outline the general method for integrating and interpreting EPD data in the EC3 tool. Methods are proposed for assessing the quality of data in EPDs, establishing estimates of EPD uncertainty and establishing approximate embodied carbon baselines by which embodied carbon performance can be evaluated against.

3.2 Estimating uncertainty from EPD results

Building industry professionals are generally unaware that the data in EPDs are not particularly precise even if reported to several decimal points. Anecdotally, LCA practitioners will note that many LCAs may have at least 10-20% uncertainty in some environmental impact categories. Simultaneously building industry targets such as LEED MR credits recognize improvements in the same order of magnitude as expected uncertainty.

The proposed methodology is designed to:

1. Prioritize third party verified EPDs for embodied carbon data.
2. Incentivize transparency in data and methods.
3. Simplify results to facilitate understanding and interpretation.
4. Incentivize supply chain specific (rather than industry average) data within EPDs.
5. Incentivize increased standardization of calculation and reporting of uncertainty in EPDs.
6. Support digital EPD data transfer.

Not all EPDs are the same. Some are quite precise (e.g. a single product produced at a single factory with supply chain specific data for over 90% of the contributing impacts) and others are relatively imprecise (e.g. industry average data for multiple products and multiple facilities calculated with industry average data for major upstream components). Per ISO 21930, “The information provided for any comparison shall be transparent to allow a clear understanding of the limitations of comparability” highlights a core objective of the EC3 tool: recognizing that people are attempting to use EPDs for comparison, EC3 transparently highlights the limitations of comparability of products. Extracted from ISO 21930:2017:

> The larger the variance among the products covered by an average EPD, the less the average represents the intended typical product. The selection of products to be covered in an average EPD should be made in such a way that the resulting average EPD is reasonably descriptive for the products covered in the average EPD when considering the use of the average EPD information in an overall assessment of a construction works.
>
> Average EPDs, for example EPDs from trade associations, shall describe what they represent. This means, as a minimum, providing details on the variation in the composition of the product compared with the average product. Such information shall give the user an indication, either qualitatively or quantitatively, of the range of results that are likely for the products covered by the average EPD. See Annex B for examples of average EPDs.

ISO 21930:2017 requires that EPDs of industry average products not differ by more than 10% and that assumptions must be conservative. Additional requirements for comparability of EPDs highlight that they must be in the context of ‘the construction works’ and thus EPDs are only comparable in the context of the full life cycle of the project. For components (e.g. materials in EC3) the key issues (adapted from ISO 21930:2017 section 5.5) are summarized in Table 2.

Table 2. Key issues in EPDs.

Issue	Addressed in EC3
Functional equivalence	EPDs are categorized by product type and sortable based on performance attributes. EC3 to provide guidance to users on the need to access whole building LCA tools when comparing dissimilar products. Additional professional judgement is required by users of the EC3 tool to assess equivalence.
Type and amount of materials	Products are sorted by material category and GWP is normalized by declared unit.
Life cycle stages and scenarios are used are the same	Tracking A1-A3 results at this time. Tracking PCRs for EPDs in EC3.
Biogenic carbon treated consistently and completely	Given that most current wood product EPDs do not fully report biogenic carbon, EC3 will provide estimates of biogenic carbon based on data within EPDs and attempt to treat all EPDs consistently.
The influence on the use stage should be taken into account or are the same	As EC3 focuses on specification and procurement *within* a product category, the use stage impacts should be the same. Where use stage impacts may be different within a certain category, EC3 strives to highlight these issues for users and point them to resources such as whole building LCA tools to enable adequate comparisons. The insulation category presents the most challenges in this area within the nine categories being released in the public beta.
Module D shall not be aggregated with other LCA stages.	EC3 does not include Module D at this time.

3.3 Data quality assessment

In order to use EPDs for comparison, the quality of the data in EPDs needs to be assessed. EC3 proposes using a standardized method to assess data quality in EPDs built on a 'Q Metadata for EPD' methodology. Q Metadata is a method for assuring data quality in EPDs, developed to enable comparisons in product procurement policies[11]. shows the 'LCA staircase' highlighting that with increased ambition (e.g. comparison for public procurement) comes increasing responsibility for LCA data quality.

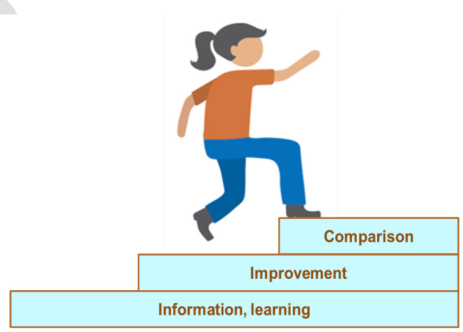


Figure 5. LCA staircase of levels of data quality.

The EC3 team reviewed various methods of evaluating LCA data quality and identified this method as the most relevant and relatively simple to implement given that the team only had access to published EPDs and not associated background reports.

[11] Erlandsson, M. (2019). *Q metadata for EPD.* Smart Built Environment.

The Q-Metadata method evaluates EPDs on the following criteria (quoted directly):

1. Is it for a unique product or product group;
2. Is it for one specific manufacturer or several;
3. Is the environmental data based on specific process data or generic (database) data;
4. How is the environmental indicator result verified;
5. Are significant assumptions made in the underlying LCA;
6. If the EPD is not certified how is the indicator result calculated; and
7. Who is responsible for establishing the Q metadata for the current product.

The EC3 tool will adapt the first three Q-Metadata criteria to assess the representativeness of the EPD. The default assumptions for each product category will be editable in EC3 by program operators to verify and correct, if necessary.

3.4 Estimating EPD precision

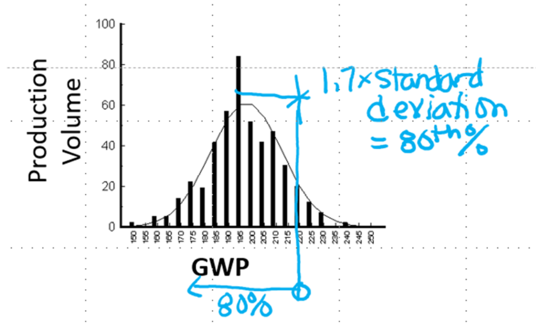
There are two primary sources of imprecision in EPDs: uncertainty in the underlying data (e.g. the actual emissions from driving a diesel truck) and known variability (e.g. use of average data that represents a range of possible manufacturing processes). Reducing uncertainty is best done through alignment and improvement of datasets. Standardizing an LCI dataset for North America and consistently using this dataset could help decrease uncertainty. The EC3 tool is focused on estimating precision of EPDs in order to drive industry toward developing more representative EPDs through the use of supply chain specific upstream data (e.g. the actual estimate of emissions when producing the nylon used in a carpet rather than an estimate of the average impact of producing nylon).

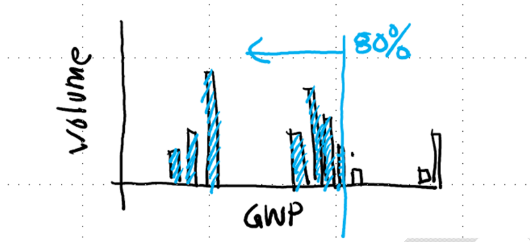
ISO standards (ISO 21930:2017) require reporting of variability, however there is little clarity on how to do so. Thus, a range of methods are expected to be used in reporting EPD variability in the future. Until this data is broadly available in EPDs, the EC3 tool creates conservative estimates of these impacts.

The EC3 tool recommends that EPDs report variability of A1-A3 GWP impacts with the following metrics to two significant digits:

- Mean
- Median
- If 10 or more suppliers: 20^{th} and 80^{th} percentile (see figure 1 below)
- If less than 10 suppliers: min and max

All EPDs report uncertainty with a 90% confidence interval around the mean using Monte Carlo simulation based on accepted LCA data methods.

<table>
<tr><th colspan="2">PROBABILITY DENSITY FUNCTION: Recommendations on reporting/interpreting variability in EPDs.</th></tr>
<tr><td>

a. Near ideal ‘normal’ distribution function (‘bell curve’)


b. PDF for material with two primary production methods</td><td>An ideal method to better understand the range and distribution of embodied carbon (EC) impacts of a product type would be to have data on the production volume for different products with different GWP. A probability density function (PDF) plots the volume of material produced for each different EC value.

Figure ‘a’ represents a PDF in which the majority of products are produced at the ‘average’ GWP and relatively few products are at the high and low values. Note that if the shape of the PDF is known, the 80^{th} percentiles can be estimated using the standard deviation.

Figure ‘b’ represents a product type with two production methods such as one with high recycled content and another with higher virgin material and resulting higher carbon impact. While data of this type can be used to calculate a standard deviation, without the PDF or a curve fit, the standard deviation is not particularly useful in making decisions.</td></tr>
</table>

Figure 6. Exploring variability and probability density functions.

4 Setting embodied carbon baselines and uncertainty

All EPDs in the EC3 tool will have:

1. A baseline value representing a conservative assessment of high embodied carbon in the product category, and
2. An estimated uncertainty presented alongside the published value.

This section explains how these values are developed.

4.1 Baselines

Baselines serve as a point of reference for evaluating performance for a group of similar items. In the EC3 tool, baselines are meant to serve as a conservative estimate of the upper bound for embodied carbon in a product category.

Given that most material product categories currently lack industry-wide statistical embodied carbon data, the Carbon Leadership Forum is estimating these baselines using one of three methods, depending on the quality of available data for a material product category:

1. *Method 1:* If a material category has very few EPDs (less than 10) in the EC3 database or if the available EPDs are understood to not represent the full breadth of the market, then the Carbon Leadership Forum will estimate the baseline to be the midpoint between an industry-average

value and an industry-high value for the material category or product sub-type. The industry-average or industry-high values will be obtained from industry-wide EPDs or the Inventory of Carbon and Energy (ICE)[12].

2. *Method 2:* If a material category has many EPDs (more than 10 in the EC3 database), the results of the EC3 tool will be directly used to estimate the baselines.
    - Option 1: Extract data directly from the EC3 tool representing the 80th percentile of the distribution of the EPD data in the EC3 tool at a set time. Note that this is an approximation of the 80th percentile due to the lack of data on industry production volumes, which would be needed to make a production-weighted calculation. This method could be appropriate for material categories such as carpet for which there are hundreds of EPDs representing multiple suppliers and a broad range of product types.
    - Option 2: Review the spread of data within the EC3 tool. Evaluate if different product types and performances skew to higher or lower numbers. Select a baseline informed by data within the EC3 tool including both embodied carbon statistics and category-specific issues. **[This is how Method 2 is applied to obtain the Beta Baselines.]**
3. *Method 3:* If industry specific data exists regarding the range of the emissions in this product category, the ranges used will be extracted from that data source.

None of these methods are statistically exact. Due to the current scarcity of information on industry production quantities and the unequal representation of high- and low-carbon products in the current selection of available EPDs, these methods are approximations to use until better data exists. The method of selecting the baselines and the selected baselines are included in the CLF Beta EC Baseline document. Ideally this data would be provided directly from LCA studies that have access to the industry specific production and emissions data.

4.2 Uncertainty

In an ideal world, EPDs would be highly representative and precise, reflecting the exact supply-chain impacts of the products they represent. However, most EPDs rely on data that are much less specific but more readily available to LCA practitioners. Using the 'burden of the doubt' methodology, the uncertainty is presented alongside the declared value and added to the declared value when sorting EPDs.

In cases where the underlying uncertainty is calculated and declared in an EPD, the EC3 tool will present the verified uncertainty declared by the EPD.

For EPDs that do not declare uncertainty, the EPDs are evaluated in the EC3 tool in order to estimate uncertainty. Ideally this uncertainty and variability would be reported from the underlying LCA.

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12 Circular Ecology, *Embodied energy and carbon - The ICE database V3.0 Beta*, 2019 < http://www.circularecology.com/embodied-energy-and-carbon-footprint-database.html#.XdDAHVdKjD4> [accessed 16 November 2019]

The following list of factors, based on Q metadata,[13] is proposed to characterize the level of data specificity in an EPD, thus estimating the level of uncertainty:

1. Is the EPD **manufacturer-specific** (as opposed to representing an industry or sector)?
2. Is the EPD **facility-specific** (as opposed to representing an average of multiple, or facilities with different efficiencies, energy supplies, and/or supply chains)?
3. Is the **EPD product-specific** (as opposed to capturing a range of products which may have different inputs or proportions)?
4. Is the **EPD temporally-specific** (reflecting the process and supply chain as it existed at a particular time)?
5. How **upstream-specific** is the EPD (i.e. how closely do the upstream datasets reflect actual processes, or are the data represented by an industry average)?

NOTE: At the time of the Beta launch, only the first three factors are adjustable between EPDs in the EC3 tool. Factors 4 and 5 are the same for all EPDs at this time. While one expects that variation is not the same among all material/product categories, all categories are being assessed the same at the Beta launch.

The methodology for how EC3 will quantify the uncertainty associated with these variable factors is described in the following subsections.

4.2.1 Methodology

In the EC3 tool, the names of the factors describing the variability of the underlying data and their options are defined as follows:

1. *ManufacturerSpecific:* true or false (corresponds to Q metadata Criteria #2: Manufacturing Representativeness)
2. *FacilitySpecific:* true or false (corresponds to Q metadata Criteria #2: Manufacturing Representativeness)
3. *ProductSpecific:* true or false (corresponds to Q metadata Criteria #1: Product Comparability)
4. *TemporalRelevance:* true or false (corresponds to Q metadata Criteria #1: Product Comparability) labeled 'just in time' in the EC3 tool at Beta launch.
5. *DataRepresentative:* Percentage of upstream data that is "representative data from the actual processes that are collected" (corresponds to Q metadata Criteria #3: Data Accuracy) labeled 'supply chain specific' in the EC3 tool at Beta launch.

Note that there is some overlap between the variables. One variable is likely correlated with another variable, which is likely correlated with another variable, and so on. This chain of dependency between the variables means that they are "nested variables." Accounting for this interdependency or correlation between variables adds additional complexity to the uncertainty evaluation. In the absence of a full sensitivity analysis, the uncertainties from the different factors are assumed to be independent of each

[13] Smart Built Environment, *Q Metadata for EPD*, 2018 <https://www.ivl.se/download/18.57581b9b167ee95ab99345/1547122416899/C363.pdf> [accessed 4 July 2019].

other. Therefore, for the sake of simplicity, the interdependent nature of these variables is ignored in this method.

The root-mean-squared method is used to combine the uncertainties from all of the factors, producing a set of +/- uncertainty values for the EPD. *Z* is used to symbolize uncertainty[15] and is being represented as a percentage above or below the reported average data. *Z* for the overall EPD, z_{EPD}, is calculated by summing the variance (z^2) of each factor and taking the square root:

$$z_{EPD} = \sqrt{z_M^2 + z_F^2 + z_P^2 + z_T^2 + z_R^2}$$

Ideally, the uncertainty values associated with each factor would be customized for each material category. However, at the time of this writing, there were not enough industry LCA data to develop material-specific uncertainties. For the time being, the uncertainty values described will be used as the default, and if supporting industry data is available in the future, material-specific factors will be developed for each material.

4.2.1.1 Z_M: Manufacturer specificity

This factor captures whether an EPD is manufacturer-specific, as opposed to representing an industry or sector.

Table 3. Uncertainty factors for Z_M.

Option	Conditions	+z	-z
TRUE	TRUE if: • Products in the Declaration are declared by only ONE organization, AND • That organization owns the facility at which the relevant product is made	+2%	-2%
FALSE	FALSE for all other conditions other than the TRUE condition described above. This includes EPDs that are described as representing a “sector” or an “industry.”	+20%	-20%

4.2.1.2 Z_F: Facility specificity

This factor captures whether an EPD or data within an EPD is facility-specific, as opposed to representing an average of multiple facilities, or facilities with different efficiencies, energy supplies, and/or supply chains.

[15] In statistics, *z* is typically used to represent the distance from the mean as a percentage, calculated by dividing the standard deviation by the mean.

Table 4. Uncertainty factors for Z_F.

Option	Conditions	+z	-z
TRUE	TRUE if: • ManufacturerSpecific = TRUE, AND • Only ONE manufacturing facility used the declaration or data point to declare products.	+2%	-2%
FALSE	FALSE for all other conditions other than the TRUE condition described above.	+20%	-20%

4.2.1.3 Z_P: Product specificity

This factor captures whether an EPD or data within an EPD is product-specific, as opposed to capturing a range of products which may have different inputs or proportions. If the LCA results are expected to vary by less than 10%, an EPD is considered product specific in the Beta release. Ideally EPDs would report this variation by product group that would supersede these default factors.

Table 5. Uncertainty factors for Z_P.

Option	Conditions	+z	-z
TRUE	TRUE if: • ManufacturerSpecific = TRUE, AND • The declaration or data point describes a single performance specification, AND • No other product used the same declaration or data point	+2%	-2%
FALSE	FALSE for all other conditions other than the TRUE condition described above.	+20%	-20%

4.2.1.4 Z_T: Temporal relevance

This factor captures whether or not the EPD reflects the process and supply chain as it existed at a particular time. Examples of a 'just in time' (as described in the EC3 tool) include an EPD issued alongside the batch ticket with concrete, representing the actual fabrication impacts of a steel project, a carpet factory EPD updated monthly reflecting actual facility fuel consumption etc. **Note that currently, no declarations that meet the criteria for TemporalRelevance exist in the EC3 database as there are no known EPDs developed to this level of precision.**

Table 6. Uncertainty factors for Z_T

Option	Conditions	+z	-z
TRUE	TRUE if: • ProductSpecific = TRUE, AND • The declaration describes a single run of manufacturing that is no more than 90 calendar days long, AND no other batch or product uses the same declaration	+2%	-2%
FALSE	FALSE for all other conditions other than the TRUE condition described above.	+20%	-20%

4.2.1.5 Z_R: Data representatition

NOTE: This factor is not applied in the current Beta version of the EC3 tool. All EPDs are assumed to have a Z_R =20%. For some products this is conservative and others it is not. Examples include:

- **Mineral wool insulation, over 90% of impacts are attributed to A3. Upstream data variability will have little impact, therefore uncertainty will likely be over-estimated**
- **Concrete: Cement impacts contribute to over 90% of the impacts in A1. Actual cement impacts can vary by as much as 50%, therefore uncertainty will likely be under-estimated.**

This factor reflects the uncertainty of the overall GWP of the EPD due to uncertainty in the upstream supply chain. The variable Z_R is a percentage with a positive and negative value.

The percentage values (+/-) representing the level of uncertainty associated with upstream data specificity in an EPD can be calculated (estimated) as follows:

$$Z_R = (1 - R) * Z_A$$

Where:

- R is the percentage of total GWP impact for a product that is due to process- or product-specific data, determined using one of two methods:
  1. The LCA practitioner who is the author of the EPD defines X (preferred option)
  2. EC3 estimates R (default option) as the following:

$$R = P_{A1} + P_{A2}$$

  Where:

  - P_{Ai} is the percent contribution to total GWP by life cycle stage *i*, determined using one of two methods:
    1. The program operator defines P_{A2} and P_{A3} (along with Z_{A1}) (preferred option)
    2. EC3 defines P_{A2} and P_{A3} (along with X_{A1}) (default option)
- Z_{A1} is the anticipated variation (expressed as +/- %) of component that dominates life cycle stage *A1* for a material category, determined using one of two methods:

1. An industry average EPD for a material category defines 20th and 80th percentile GWP values for life cycle stage A1 (preferred option)
2. EC3 method estimates the 20th and 80th percentile GWP values for the market.

(1-R) represents the portion of the data contributing to GWP that is generic (i.e. estimates of the industry average from LCA datasets not representing the actual supply chain of the product). Z_R does not account for the uncertainty associated with R, the portion of the data that is product- or process-specific. It should be noted that uncertainty associated with A3 is represented by the other four factors. Transportation data and distances (A2) are typically either product-specific or specified by the PCR, so they are presumed to be representative of actual processes.

An example of this process is shown in the following gray box.

Example: Calculating uncertainty for upstream data representation

For this generic example, the product is produced with four material inputs and one primary energy input and transportation.

Component	Quantity	Total GWP (kg CO2e)	% of impact	Variation (%)
Material 1	0.24	250	90%	-45%, +65%
Material 2	0.04	6	2%	+/-20%
Material 3	0.69	7	2%	+/-20%
Material 4	1.10	8	3%	+/-20%
Water	0.14	-	-	-
Manufacturing and transportation	-	-	3%	+/-2%
Total	2.21	271	100%	

1. **Determine the contribution of process-specific data to the overall GWP**.

   For manufacturing and transportation, the quantities of energy and fuel use are supply chain specific however the life cycle inventory datasets are generic. For the purposes of this analysis we assume that the most important factor for energy and manufacturing impacts is whether or not the quantities consumed are supply chain specific. Thus the 3% of impacts are assumed to have low (2%) variation.

2. **Determine the dominating contributor to GWP within A1 and its uncertainty.**

   Material 1 contributes to approximately 93% of the upstream GWP impacts, therefore it is the dominating component. Variability between the 20th and 80th percentiles for this material was reported in the EPD as -45%, +65%. For most materials this variation is not known and would need to be estimated.

3. **Calculate the upstream data uncertainty.**

$$-Z_R = (1 - 0.03) * (-0.45) = -44\%$$

$$+Z_R = (1 - 0.03) * (0.65) = 63\%$$

Thus, the uncertainty associated with upstream data specificity for this EPD is -44%, +63%.

4.2.2 Uncertainty calculation flowchart

A flowchart of the calculation process for uncertainty is shown in Figure 7.

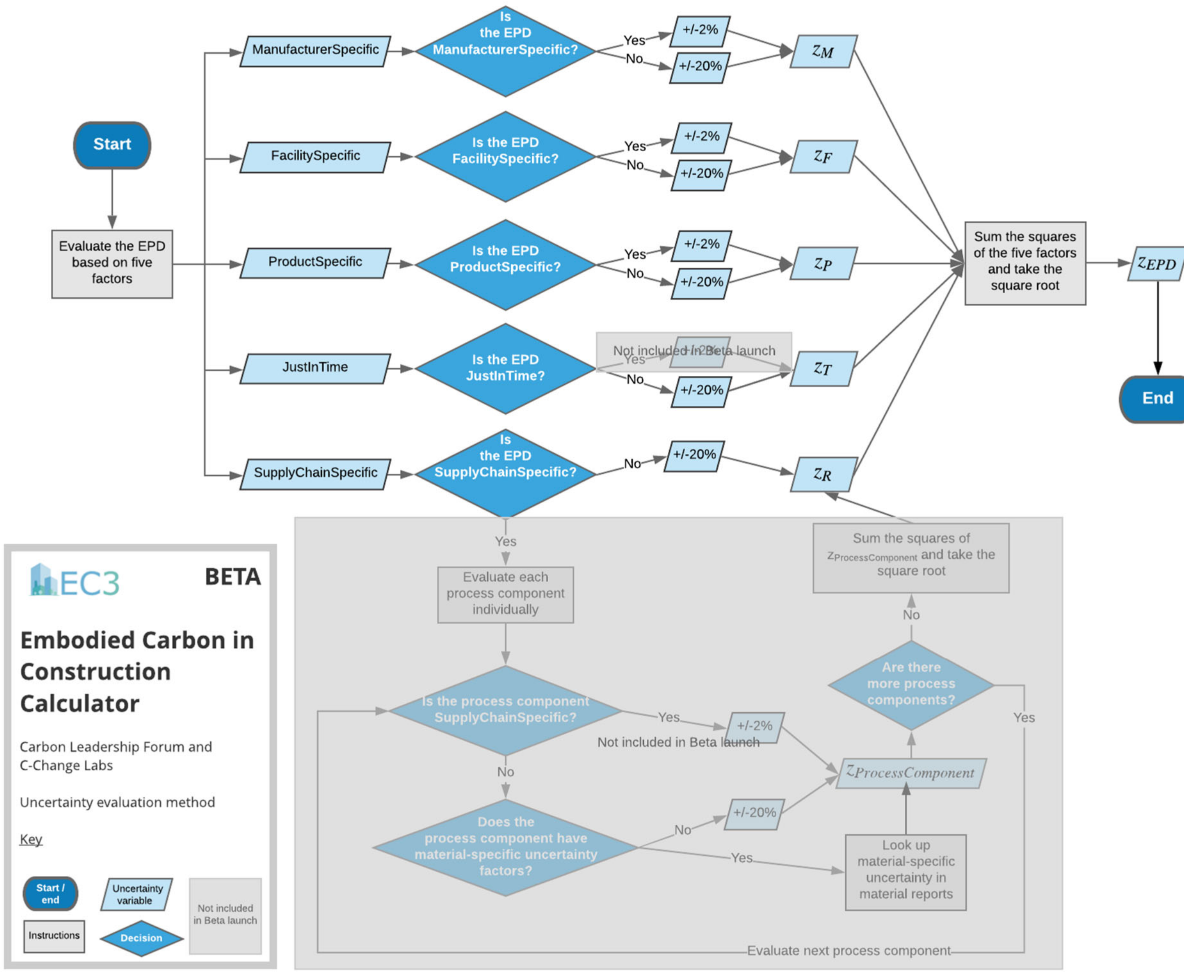

Figure 7. Calculation of overall uncertainty for EPDs in EC3. (grey boxed areas not include in Beta Release)

4.2.3 Default uncertainty factors

The default assigned percentages for uncertainty are rough approximations based on what is currently in the EC3 database. Generally, the lower-bound numbers ("TRUE" option) are 1/10th of the upper bound ("FALSE" option), which represents the reasonable best-case accuracy of data. A more detailed justification for the uncertainty factors is presented in Table 7. Each of the factors account for a mix of differences in process and supply-chain; there is currently insufficient data to treat these separately.

Table 7. Explanation of how the default uncertainty factors were developed.

Factor	Uncertainty		Explanation
	Option = TRUE	Option = FALSE	
Z_M (manufacturer)	+/-2%	+/-20%	Based on typical variation among EPDs from different manufacturers within an industry.
Z_F (facility)	+/-2%	+/-20%	Based on typical variation among facility-specific EPDs from the same manufacturer.
Z_P (product)	+/-2%	+/-20%	Based on typical variation among EPDs for products with different specifications (e.g. strength) from the same facility.
Z_T (time)	+/-2%	+/-20%	Not implemented in the EC3 tool Beta. All materials and products assigned 20%.
Z_R (representative/ supply chain specific)	+/-2%	+/-20%	Not implemented in the EC3 tool Beta. All materials and products assigned 20%.
Z_R Proposed alternative: not implemented in the EC3 tool Beta.	0% to 100%, based on individual materials		Based on the impact of different process options on the EC intensity of the output, and the variability in process factors are derived from EPDs where available, otherwise based on a document industry data source e.g. ICE. This value varies for different product categories.

4.2.4 Sample uncertainty calculation

In summary, the steps for estimating the uncertainty for an EPD that does not declare its own uncertainty are:

1. Evaluate each EPD using the factors and method presented in the following sections.
2. Combine the uncertainties from all five factors using the root-mean-squared method.

An example of this calculation process is shown in the following gray box.

Example: Calculating overall uncertainty using root-mean-squared method

Given the following conditions for an EPD, the resulting assigned uncertainties for each factor using Table 7 are:

ManufacturerSpecific = TRUE → z_M = +/-2%

FacilitySpecific = TRUE → z_F = +/-2%

ProductSpecific = FALSE → z_P = +/-20%

TemporalRelevance = FALSE → z_T = +/-20%

DataRepresentative = FALSE → z_R = +/-20%

Thus, the overall uncertainty for the EPD is calculated as:

$$z_{EPD} = \pm\sqrt{z_M^2 + z_F^2 + z_P^2 + z_T^2 + z_R^2}$$

$$= \pm\sqrt{(0.02)^2 + (0.02)^2 + (0.20)^2 + (0.20)^2 + (0.20)^2}$$

$$= \pm\, 0.35$$

Thus, the uncertainty for this EPD is +/-35%.

If the GWP value from this EPD was 100 kg CO2e, then applying this uncertainty would result in:

Low-end: (100 kg CO2e) x (1 – 0.35) = 65kg CO2e

High-end: (100 kg CO2e) x (1 + 0.35) = 135kg CO2e

Thus, the range for the EPD due to uncertainty assessment would be 65 – 135 kg CO2e.

Using the burden of the doubt method, the EC3 tool sorts based upon the conservative estimate of 135kg CO2e.