Ebook

LIFE CYCLE ASSESSMENT FOR BUILDINGS

Why it matters and how to use it

One Click LCA®
oneclicklca.com

FOREWORD

As countries accelerate their efforts to meet climate change commitments, pressure grows for the construction sector to reduce its impact rapidly. Building life-cycle assessment (LCA) is critical to doing so.

Building LCA is a science-based methodology for quantifying the lifetime environmental impacts of a building. It is used to measure and reduce the embodied, operational, and whole-life carbon of buildings. It is often needed to achieve green building certifications and comply with regulations.

While awareness of building LCA is growing, the expertise in conducting building LCA is quite limited. This leads to its potential to decarbonize construction projects not being fully harnessed. This ebook aims to change that.

Whatever your role in construction – designer, consultant, engineer, contractor, developer, owner, or policy-maker – this guide can help you with building LCA. It offers a clear introduction to building LCA, why it is important and how to effectively use it in your projects. This ebook is written by One Click LCA Ltd.

This ebook covers:

- Basic concepts of building LCA with practical examples.
- The relationship between building LCA, whole-life carbon (WLC), embodied and upfront carbon emissions.
- The business case for building LCA across the construction supply chain.
- The steps involved in performing a building LCA.
- The role of various stakeholders in decarbonizing the construction sector.

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GLOSSARY

Biogenic carbon: carbon stored in biological materials such as in wood products. Biogenic carbon within a building product can be considered as a negative carbon emission.

Carbon footprint: the sum of all GHG emissions of a given product, asset, or activity.

Characterization: characterization is the calculation of category indicator results to impact-equivalents. Example: 5 kg CO_2 and 3 kg CH_4 yield 68 kg CO_2-eq.

Characterization factor: a factor derived from a characterization model applied to convert inputs and outputs to the common unit of the category indicator. Examples: Global Warming Potential (GWP), Acidification Potential (AP).

Characterization model: a science-based model of the impact of elementary flows with respect to a particular category indicator. It provides the basis for a characterization factor.

Circular Economy: an approach which encourages reuse, recovery and recycling of materials and promotes the use of renewable resources.

Comparative LCA: an LCA which offers a comparison of different products or product variants. Different processes and production systems can also be compared.

Cut-off criteria: the criteria for the exclusion of inputs and outputs (cut-off rules) in the LCA and information modules.

Embodied carbon: emissions associated with materials and construction processes throughout the whole life-cycle of a building.

End-of-life carbon: emissions which occur after a building or infrastructure project's lifetime – whether associated with deconstruction/demolition (C1), transport from the site (C2), waste processing (C3), or disposal (C4).

Endpoint indicator: attribute or aspect of natural environment, human health, or resources, identifying an environmental issue giving cause for concern.

Environmental Product Declaration (EPD): a third-party verified report of the LCA results of a product.

Greenhouse gas (GHG): any gas in the atmosphere which absorbs and re-emits heat. The main GHGs are water vapor, carbon dioxide (CO_2), methane (CH_4)and nitrous oxide. (N_2O).

WHOLE LIFE CARBON

Upfront carbon	Use stage embodied carbon	Operational carbon	End of life carbon	Beyond the lifecycle
				As additional information

BUILDING LIFE-CYCLE MODEL ACCORDING TO EN 15804/ISO 21930

Product stage & construction (A1- A5)	Use stage (B1 - B5)	Use stage (B6 - B7)	End of life (C1 - C4)	Beyond building life-cycle (D)

Fig. 1. Overview of the terminology used

Life-cycle assessment (LCA): a science-based method of assessing the potential environmental impacts associated with a product throughout its life-cycle. When applied to a building, it is referred to as building LCA.

Life-cycle costing analysis (LCCA or LCC for short): an objective method for measuring and managing the lifetime costs of any project or asset. In construction, it enables design options to be compared from a lifetime perspective to reduce overall costs.

Midpoint indicator: indicators which focus on single environmental problems, for example, climate change or acidification.

Operational carbon: emissions associated with energy used (B6) to operate the building or in the operation of infrastructure.

Product LCA: a type of LCA which provides a descriptive analysis of the environmental performance of an individual product over its entire life-cycle.

Screening LCA: a type of LCA that provides an early, rough estimation and assessment of environmental impacts by considering the most relevant materials and resources using average data.

Upfront carbon: emissions caused in the materials production and construction phases (A1-5) of the life-cycle before the building or infrastructure is used.

Whole Building LCA (WBLCA): an LCA exercise where the entire building project is considered holistically to help designers to reduce the carbon footprint. Synonymous to building LCA.

Whole-life carbon (WLC): emissions from all life-cycle phases, encompassing both embodied and operational carbon together (i.e. modules A1 to C4, with module D reported separately).

INTRODUCTION

Climate change and the construction sector

With construction contributing around 39% of global carbon dioxide emissions, there is an urgent need for the sector to decarbonize.

Embodied carbon refers to the emissions arising from the extraction, manufacture, transportation, installation, maintenance and disposal of building materials. It contributes to approximately 11% of global CO_2. **Operational carbon** refers to the emissions from the use of the building: for example, the energy needed to heat, cool, and maintain it.

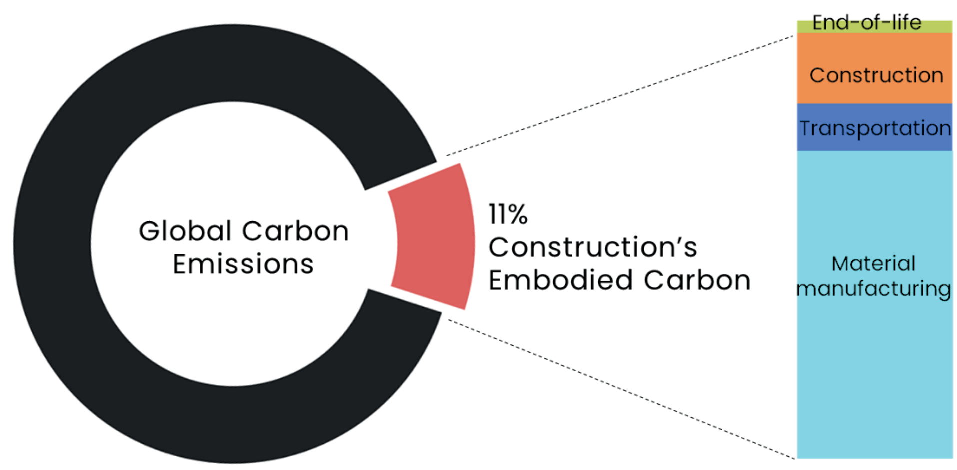


Fig. 2. Contribution of embodied carbon

Efforts to reduce the impact of the construction sector have long focused on operational carbon. Due to the rapid decarbonization of the energy sector, embodied carbon is becoming recognized as a dominant climate impact driver. In response, many countries are setting limits for embodied carbon reduction.

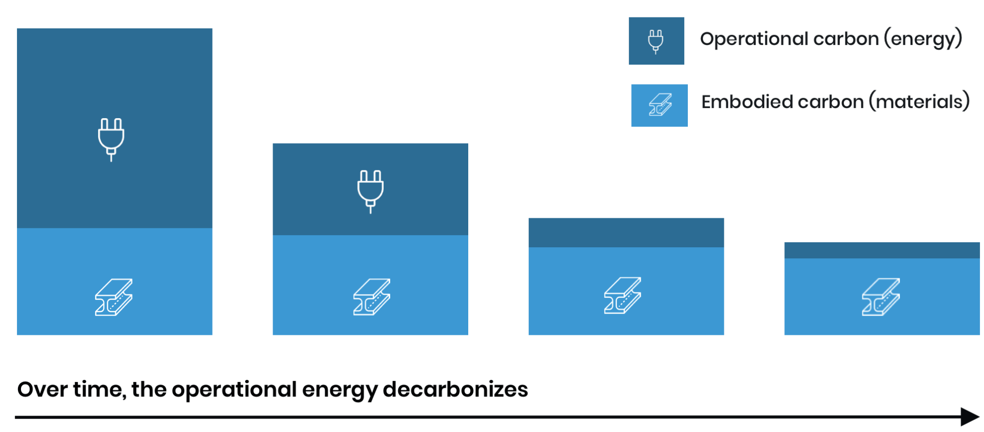


Fig. 3. Operational carbon emissions will decrease over time

Measuring and reducing carbon emissions

As a **science-based methodology for quantifying lifetime environmental impacts,** building LCA is the most effective tool available to measure the life-cycle carbon emissions of any construction project.

Building LCA is a mandatory part of planning regulations in many countries, including Sweden, the Netherlands, France and in parts of the UK. It is incorporated in several green building certifications such as BREEAM, LEED, DGNB, and Energie Carbone.

Building LCA helps to measure and reduce environmental impacts of your building, achieve green building certifications, and comply with regulations.

1. WHAT IS BUILDING LCA?

1.1 Building life-cycle stages and impacts

The different periods of a building's life are known as its **life-cycle stages**. They are referred to as **product, construction, use, end-of-life and benefits beyond the system boundary.** The standardized module designations for each life-cycle stage, from A1 to D, is shown below (Fig. 4).

A1 - A3 Product stage
- **A1** Raw material extraction
- **A2** Transport to manufacturing site
- **A3** Manufacturing

A4 - A5 Construction stage
- **A4** Transport to construction site
- **A5** Installation / Assembly

B1 - B7 Use stage
- **B1** Use
- **B2** Maintenance
- **B3** Repair
- **B4** Replacement
- **B5** Refurbishment
- **B6** Operational energy use
- **B7** Operational water use

C1 - C4 End of life stage
- **C1** Deconstruction & demolition
- **C2** Transport
- **C3** Waste processing
- **C4** Disposal

D - Benefits and loads beyond system boundary

Reuse, recovery and/or recycling potentials, expressed as net impacts and benefits

Fig. 4. Life-cycle stages of a building

The processes involved in the life-cycle stages of a building releasing gaseous, solid, and liquid emissions into the air, water, or soil can negatively impact the environment and humans.

Building LCA is a science-based methodology for quantifying the lifetime environmental impacts of a building.

1.2 Environmental assessment with building LCA

LCA assesses several **environmental impact categories,** with **Global Warming Potential (GWP)** being the most widely recognized. When only GWP is measured, the assessment is known as a carbon footprint. During LCA, emissions are converted into **environmental impacts potentials.**

The impacts are expressed in quantities of a substance that can cause environmental harm, such as greenhouse gas emissions, and known as midpoint indicators. They do not represent the actual harm, known as endpoint indicators, for example sea level rise. The most used midpoint indicators for assessing environmental impact and resource use are shown below (Table 1).

Table 1. Midpoint environmental and resource use impact indicators

Environmental and resource use indicators	Description
Global Warming Potential (GWP) Unit $kgCO_2eq$	Climate change or global warming potential due to emission of greenhouse gases.
Acidification Potential (AP) Unit $kgSO_2eq$	Acidifying emissions that result in a lower pH-value of water and soil, decreasing the nutrient availability and intake of plants.
Eutrophication Potential (EP) Unit $kgCFC_{11}eq$	Nutrient emissions (nitrogen & phosphorus) that increase the flow of nutrients to ecosystems, causing algae growth in waters.
Ozone Depletion Potential (ODP) Unit $kgCFC_{11}eq$	Describes damage caused to the ozone Layer in the stratosphere (from refrigerants). Increases harmful UV-radiation.
Photochemical Ozone Creation Potential (POCP) Unit kgC_2H_4eq	Describes the effect of substances in the atmosphere to create photochemical smog.
Abiotic Depletion Potential for Fossil Resources (ADPf) Unit MJ	Resource use indicator which describes the reduction of the global amount of non-renewable raw materials and is determined for each extraction of minerals and fossil fuels based on the remaining reserves and rate of extraction.

1.3 LCA in different project stages

A building goes through several phases: **concept design, detailed design, construction and procurement, and use phase**. The level of detail required for carrying out LCA depends on the data available at each stage.

A **screening LCA** is usually performed in the concept design phase to identify material and building element hotspots, using available data. A **comparative LCA** can be performed at the detailed design stage and uses more accurate and relevant data to choose the best design alternatives. The most accurate LCA is performed after the construction and procurement stage using the actual material quantities and information about the exact materials. Fig. 5 shows the solutions for each project phase.

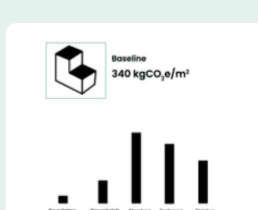
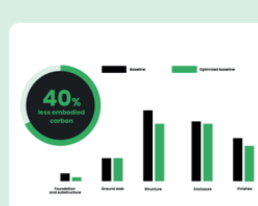
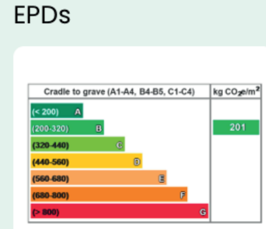
	CONCEPT DESIGN	DETAILED DESIGN	PROCUREMENT	USE STAGE
Construction stages	Sketch or concept 	BIM model 	Building in construction 	Building in use and adaptation 
Material quantities	Data can be obtained from cost estimation tools or early design tools like Rhinoceros 3D, Tekla Structural Designer. Alternatively, model can be generated with Carbon Designer.	Detailed design drawings or BIM models.	Construction drawings, BIM models and cost plans of final materials.	Actual quantities.
One Click LCA workflow	Carbon Designer baseline 	Compare designs 	Benchmarking Select best products from manufacturers EPDs 	Interior fit outs and refurbishments 

Fig. 5. One Click LCA solutions for each project stage

LCA performed early in the design process results in the highest carbon reductions and lowest costs. As the project progresses, the ability to reduce carbon decreases drastically (Fig. 6).

Carbon reduction potential

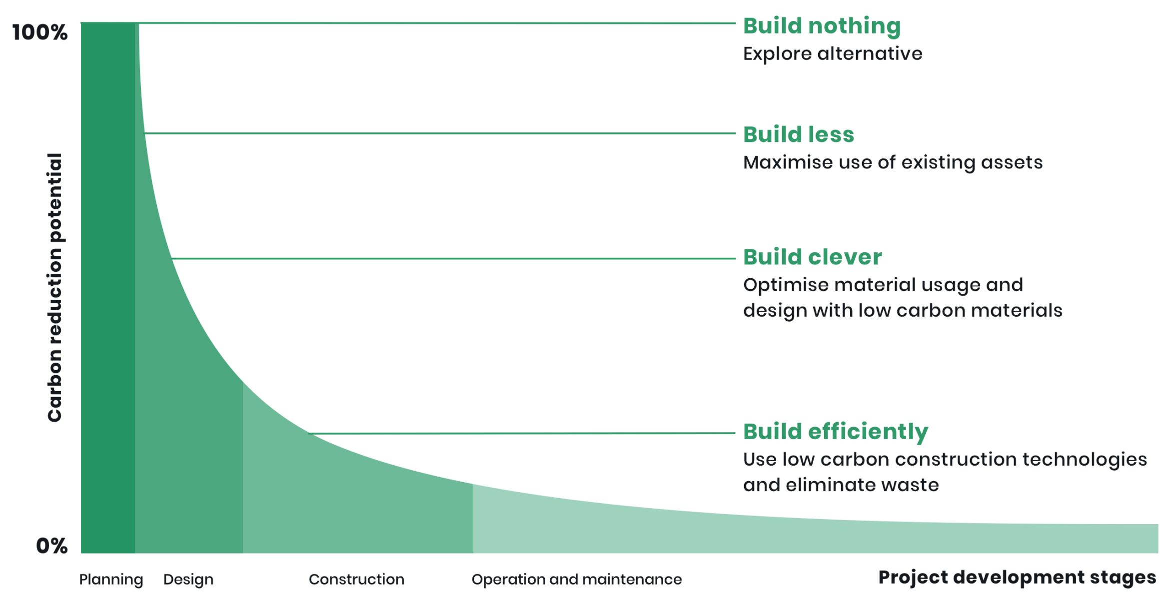


Fig 6. Opportunities to reduce embodied carbon reduces as the project progresses (Decarbonizing construction, 2021, WBCSD)

2. BUSINESS CASE FOR BUILDING LCA

By far, the most common goal for the use of building LCA is **decarbonizing the construction sector and ensuring competitiveness in an increasingly carbon-aware market**. With the growing focus on embodied carbon and achieving net zero carbon targets, investors, end-users, and tenants are increasingly looking for ways to assess and reduce the lifetime environmental impact of their projects. Conducting a building LCA demonstrates a commitment to measuring and reducing the environmental impact of construction projects. It also provides sound market advantages for actors across the supply chain. You can read more about the business case for building LCA here.

Summary of business benefits of building LCA

01 QUANTIFYING ALL CARBON-EMITTING AND CARBON-REDUCING OPTIONS

02 ACHIEVING GREEN BUILDING CERTIFICATIONS

03 COMPLYING WITH REGULATIONS

04 SUPPORTING CARBON-INFORMED DECISION MAKING

05 REDUCING PROJECT COSTS THROUGH INCREASED MATERIAL EFFICIENCY AND WASTE REDUCTION

06 QUANTIFYING CORPORATE LEVEL EMISSIONS WITH A SCIENCE-BASED APPROACH

Depending on your role within the construction supply chain – investor, designer, engineer, or consultant – the business drivers for performing LCAs may vary. In this section, we will focus on some of the main ways it is achieved.

2.1 Decarbonize construction projects

Incorporating a life-cycle perspective in projects can help project owners attain carbon reductions and transparency, regulatory compliance and certifications. Moreover, it is needed to meet the net-zero and low carbon targets which end-users, investors and tenants value. Various stakeholders across the construction supply chain are working towards decarbonizing their projects. Some examples are given below (Table 2).

Table 2. Approaches/methods used to decarbonize construction projects

Methods	Business case	Software solutions
Screening for hotspots	A whole building LCA allows for hotspot screening at every design stage.	One Click LCA for Buildings
Net zero carbon design	Net zero carbon is a requirement in multiple certification and regulatory compliance. A net zero assessment streamlines the reporting process and gives a clear value on what must be offset.	Net Zero Carbon Tool
Comparative carbon and cost optioneering	Reduce time spent in investigating trade-offs between sustainable alternatives and cost effectiveness.	Life Cycle Costing
Interior design and tenant improvement	An LCA for interior refurbishments can estimate impacts due to such refurbishments and provide guidance to support selecting the most suitable materials and reduce impact.	Interior Design Carbon Tool
Building circularity assessment	A circularity assessment supports the requirements of HQE Economie Circulaire, the London Plan Circularity Statement, and the Ellen McArthur Foundation Circularity Indicators, as well as credits in BREEAM Mat 06, 05 and 03, and Man 03.	One Click LCA Building Circularity Tool
Climate strategy-GHG reduction	Can be used to implement a greenhouse gas emissions tracking and reduction program in any sector, including primary resources, manufacturing, and services.	GHG Reporting Tool
Material selection and specification	Fully documented low-carbon materials can provide transparency and ease the material specification process in later stages.	One Click LCA for Buildings
Opportunities for refurbishment	Evaluate the trade-offs between refurbishment and new construction. Examine the options for embodied carbon, operational carbon, and cost.	One Click LCA Carbon Designer

2.2 Regulatory compliance

Governments are increasingly recognizing the need to legislate and reduce whole-life carbon in construction. As a result, building LCAs are now a mandatory part of several existing and future regulations. A list of the governments driving the embodied carbon agenda is given below (Table 3). For further details, refer to our article on Unregulated energy use and carbon emissions from buildings – and how it is changing.

Table 3. Regulations driving building LCA and embodied carbon calculation.

Jurisdiction	Regulations	Status	Timeline
Vancouver, Canada	Life-cycle emission reporting requirement, limits by 2030	Mandatory	In force
Minnesota, U.S.	State-funded projects must reduce impacts by 10%	Mandatory	In force
California, U.S.	Placing limit values on certain materials for state agencies	Mandatory	In force
Belgium	National LCA requirement for state government buildings	Mandatory	In force
Denmark	National life-cycle carbon limits on new buildings	Mandatory	2023
Finland	National life-cycle carbon limits on new buildings	Mandatory	2025
France (RE2020)	National life-cycle carbon limits on new buildings	Mandatory	2022
Netherlands	National life-cycle impact limits on new buildings	Mandatory	In force
Sweden (Klimatdeklaration)	National carbon reporting for new buildings, limits by 2027	Mandatory	2022
London, UK	Greater London Authority requirement for new projects	Mandatory	In force
Germany	National LCA requirement for federal government buildings	Voluntary	In force
European Union	Sustainable finance taxonomy criteria for large buildings	Voluntary	In force
Canada	National LCA requirement for federal buildings, limit by 2025	Mandatory	2022
New Zealand	National life-cycle carbon limits on new buildings	Undefined	Open
United States	National materials LCA requirement for federal buildings	Undefined	Open
Toronto, Canada	Whole building LCA demonstrating 20% embodied carbon reduction from baseline required for all city-owned developments	Mandatory	2022
Colorado, U. S	Requires policies to be created that set GWP/emissions limits for key construction materials in federal construction and infra projects.	Mandatory	2024

2.3 Achieve certifications

For a building LCA to contribute toward achieving BREEAM, LEED, HQE, E+C- or other green building certifications, its results must be tailored to the relevant scheme, including life-cycle stages, impact indicators, benchmarking, and more. The use cases for a few of the most popular certifications are described below (Table 4). The One Click LCA website provides more guidance on compliance and certifications.

Table 4. List of green building certifications

Certifications	Requirements	Details
BREEAM International (Similar to BREEAM Sweden, Norway and Spain)	Perform a high-quality whole building LCA analysis.	One Click LCA complies with BREEAM International (details can be found here) and delivers up to 15 credits
BREEAM Norway **BREEAM Netherlands**	Credits are awarded based on impact reductions achieved.	One Click LCA complies with BREEAM NOR and NL and delivers up to 14 credits (details can be found here: BREEAM NOR, BREEAM NL)
BREEAM UK	Perform a range of comparisons for different building elements at different stages.	One Click LCA complies with BREEAM UK and delivers up to 18 credits (details can be found here)
LEED	Complete a whole building LCA. Additional credits are awarded based on the demonstrated impact reductions and by incorporating building reuse and/or salvage materials into the project's scope of work.	One Click LCA supports LEED v4.1, v4, v3 and delivers up to 10 credits (details can be found here).
DGNB DE, DGNB International and DK	Perform a whole building LCA and demonstrate impact reductions.	One Click LCA can be used for DGNB DE, DGNB International, and it is also pre-approved for multiple DGNB DK versions (details can be found here).
Energie Carbone	Undertake a whole life-cycle assessment for the building permit and post construction. The assessment accounts for materials, construction site, energy, and water impacts. The results are then benchmarked against carbon level thresholds.	One Click LCA's LCA module for Énergie Carbone is certified in accordance with the E+C- label (details can be found here).
Level(s)	Measure GHG across a building's life cycle, demonstrate resource-efficient and circular material life-cycles, optimize life-cycle cost and value.	One Click LCA can fully support almost all Level(s) macro-objectives (details can be found here)

3. HOW TO PERFORM A BUILDING LCA

The major steps involved in performing a building LCA (according to ISO 14040) are shown below (Fig. 7). Each step is described in detail in subsequent sections.

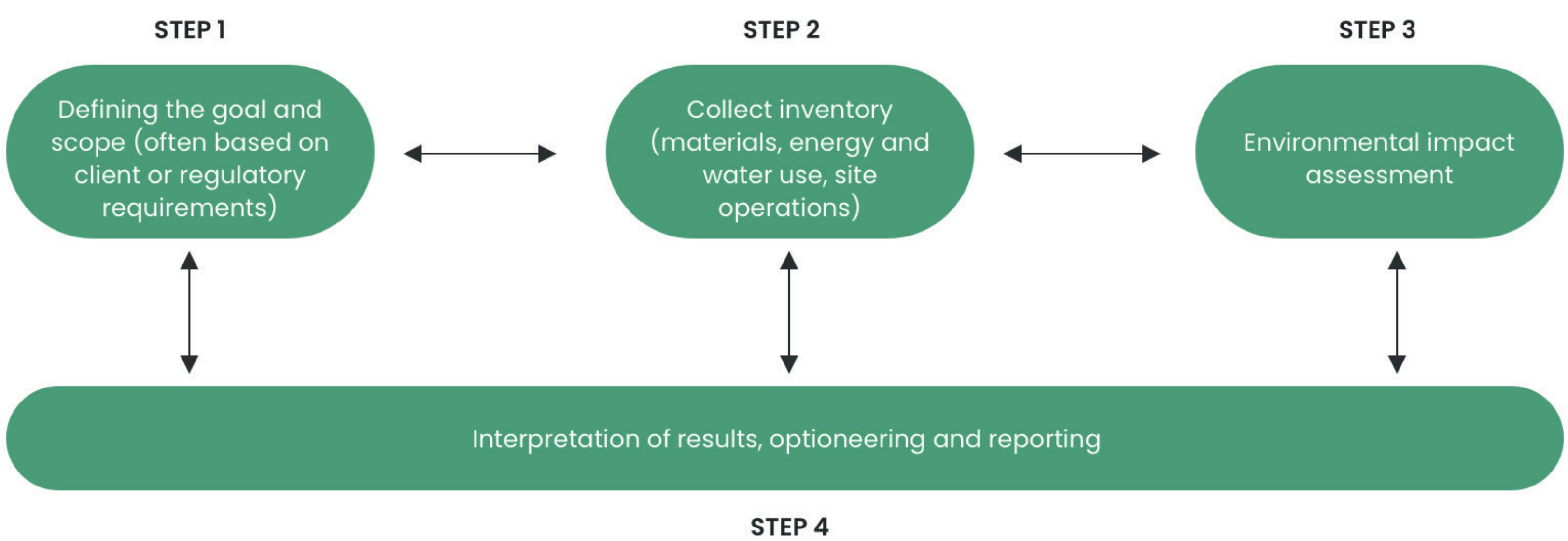


Fig. 7. Steps involved in conducting a building LCA

3.1 Step 1: Define goal and scope

Several reasons for conducting a building LCA include quantifying emissions, achieving certifications, and complying with regulations. They often define the goal and scope of the analysis as described below.

Defining goal

The general goal is to measure and reduce a building's environmental impact, but specific goals can be identified based on your requirements (mentioned previously in the business case section).

Defining scope

The LCA scope defines the areas to be included or excluded from the LCA analysis, and is usually defined by the overall goal. For example, if the goal does not require the evaluation of whole-life carbon, you can limit the extent of your analysis. The items included under the scope are system boundary (includes building area, scope and service life, site scope, and life-cycle stages and the service life of the building).

System boundary

For building LCA, the life-cycle scope is specified according to the standardized module designations (A1, A2, A3... through D) as defined in EN 15804 and ISO 21930 (Fig. 8).

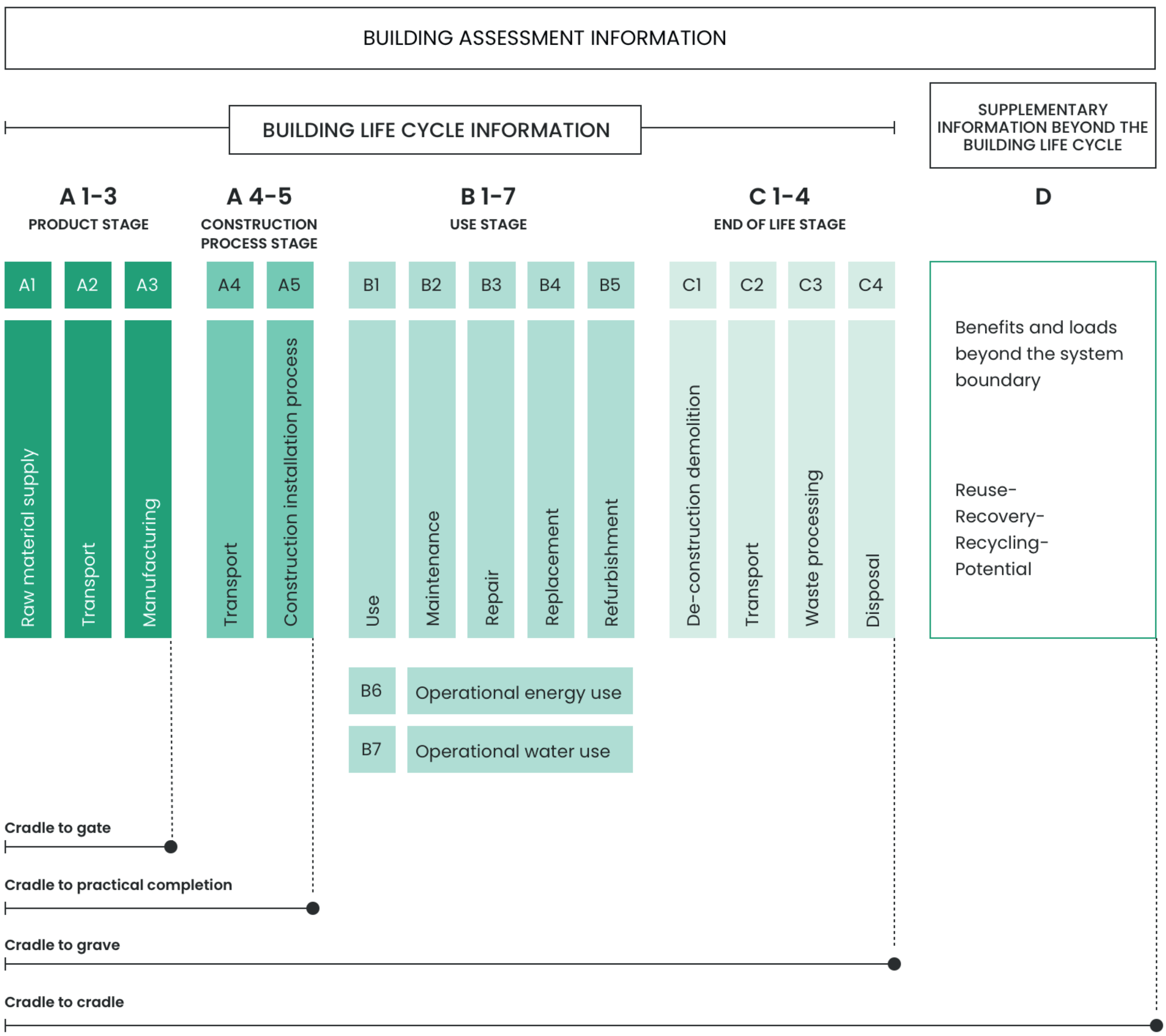


Fig. 8. Life-cycle scope specified according to the standardized module designations

The scope can be restricted to meet the requirements (certifications or regulations), as shown below.

Scope	Cradle-to-gate	Cradle-to-grave	Cradle-to-cradle
Life-cycle stages	A1-A3	A1-C4	A1-D
Examples	Product LCA	LEED	BREEAM, RICS, GLA

The building area

Gross Internal Floor Area (GIFA) is used in most popular certifications (LEED, BREEAM). It is used to calculate the LCA impacts per floor area and for the purpose of benchmarking. Refer to this article for other building area definitions used to fill the building area query.

The service life of the building

The environmental impacts are calculated over this time frame. It is typically dependent on the LCA methodology and standards or can be set based on the property owner's requirements.

3.2 Step 2: Collect Inventory

The information needed to perform building LCA is known as the life-cycle inventory (LCI). The inventory can be broadly classified into building **materials and operations.**

Building Materials: Includes information about the type, quantity, lifespan, and life-cycle stage of the building in which the material is used. This information can be generally obtained from cost plans, drawings, and BIM models. Design tools such as Revit, Tekla, Rhino and Grasshopper can be used for material quantities related information.

Building operations: Includes transportation details, material replacements, energy and water consumption, and end-of-life scenarios. This information can be obtained from designers, contractors, and project owners. The energy consumption can be tracked separately using energy tools such as IES, DesignBuilder, IDA ICE, etc.

LCA tools, such as One Click LCA, can simplify the inventory collection process by importing materials, providing ready-to-use scenarios and database (see table 5). One Click LCA can support integration with design data from BIM, IES-VE, Excel and more (details can be found here)

Table 5. Details of inventory analysis in One Click LCA

Inventory	Source of inventory (varies by module used)	Required for
A1 - raw material extraction/supply **A2** - transport to the manufacturing site **A3** - manufacturing	Bill of materials (BOM) are manually inputted, imported from BIM models or cost schedules or created with Carbon Designer, possibly completed with One Click LCA default structures.	Level(s), LEED, BREEAM, RICS, GLA.
A4 - transportation scenarios **A5** - construction installation process	One Click LCA provides appropriate default values for transport distances, which can be used when a specific source is not known.	Level(s), LEED-only A4, BREEAM, RICS, GLA.
B1 - installed products **B2** - maintenance **B3** - replacement **B4** - repair **B5** - refurbishment	B1-B3 are based on user input of quantities. B4 and B5 are based on default material service life settings and the asset calculation period.	Level(s)- except B2, LEED (only B3, B4-B5), BREEAM, RICS, GLA, (only B4, B6)
B6 - details of annual electricity, fuel, and energy consumptionIncludes district heating and cooling	Based on user input of consumption quantities. In One Click LCA database, the impacts of electricity and district heat are based on the energy production fuel mixes provided for each country by IEA, or local and regulatory sources..	Level(s), BREEAM, RICS, GLA.
B7 - estimated annual water consumption during the operational stage of the building	Based on user input of consumption quantities.	Level(s), BREEAM, RICS, GLA
C1-C4 - details of processes that occur during and after the building or asset is demolished	Based on options such as Material-locked and End of life (EOL) scenarios. EOL processes are based on regulatory scenarios. For non regulatory tools, One Click LCA provides its own end of life default processing methods for various materials.	Level(s), BREEAM, RICS, GLA.
D - includes reuse and recovery of materials and energy, based on their recycling potential **D2** - is the exported energy	Based on the material and on the end-of-life process that is chosen.	Level(s), BREEAM, RICS, GLA.

Cut-off criteria: The total of neglected input flows allowed per module, e.g., per module no more than 5 % of energy usage and mass can be neglected for each module, A, B, C, or D. Different compliance modules may limit allowable cut-offs.

LCA data

Once the building information-related queries are filled in, mapping each material to its respective environmental profile is the next step. This process is simplified by using **LCA data** which contains information about the environmental impacts of each material of interest.

> **Building LCA uses EPDs and generic data, which are pre-characterised according to characterization methods (read more about characterization in the Appendix).**

An **Environmental Product Declaration (EPD)** provides an independently verified summary of the environmental impact of a product throughout its life-cycle, calculated via LCA. Single product EPDs are the most common type, but group and industry average EPD are available. Below is a summary of when these EPD types can be used.

1. **Single product and manufacturer EPD:** One product and manufacturer.
2. **Product group EPD:** Average of very similar products, one manufacturer.
3. **Industry average EPD:** One product and several manufacturers.

A sample EPD generated with One Click LCA pre-verified EPD generator is shown below (Fig. 9).

Sample EPD generated with One Click LCA Pre-Verified EPD Generator

GENERAL INFORMATION

MANUFACTURER INFORMATION

Manufacturer	Rearden Steel
Address	Philadelphia, Pennsylvania, United States
Contact details	John Galt john.galt@reardensteel.com
Website	www.reardensteel.com

PRODUCT IDENTIFICATION

Product name	Rearden Metal
Product number / reference	RM-001
Place(s) of production	Philadeplhia, PA, United States

EPDs of construction products may not be comparable if they do not comply with EN 15804 and if they are not compared in a building context.

EPD program operator	Program operator name here
EPD standards	This EPD is in accordance with EN 15804+A2 and ISO 14025 standards.
Product category rules	The CEN standard EN 15804+A2 serves as the core PCR. Program operator PCR here.
EPD author	Bionova Ltd, Suvilahdenkatu 10 B, 00500 Helsinki, Finland
EPD verification	Independent verification of this EPD and data, according to ISO 14025: ☐ Internal certification ☑ External verification
EPD verifier	Werner Verifier
EPD number	00001
ECO Platform nr.	-
Publishing date	29 June 2020
EPD valid until	28 June 2025

ADDITIONAL ENVIRONMENTAL IMPACT INDICATORS – EN 15804+A2, PEF

Impact category	Unit	A1	A2	A3	A1-A3	A4	A5	B1-B7	C1	C2	C3	C4	D
Particulate matter	Incidence	3.16E-06	2.86E-07	1.40E-07	3.59E-06	3.64E-07	MND	MND	4.10E-07	2.26E-07	2.14E-06	8.76E-08	-1.02E-06
Ionizing radiation, human health	kBq U235e	3.66E+00	3.09E-01	2.10E+00	6.07E+00	3.92E-01	MND	MND	9.89E-02	2.44E-01	1.51E-01	6.33E-02	-1.20E+00
Eco-toxicity (freshwater)	CTUe	1.77E+01	2.16E+00	2.03E-01	2.01E+01	2.74E+00	MND	MND	1.20E-01	1.70E+00	1.82E-01	8.80E-02	-2.14E+00
Human toxicity, cancer effects	CTUh	8.81E-08	1.22E-09	1.11E-09	9.04E-08	1.54E-09	MND	MND	4.29E-10	9.59E-10	6.43E-10	1.96E-10	-5.48E-08
Human toxicity, non-cancer effects	CTUh	2.21E-06	7.69E-08	7.74E-08	2.36E-06	9.76E-08	MND	MND	8.96E-09	6.07E-08	1.35E-08	7.45E-09	-8.45E-07
Land use related impacts/soil quality	-	8.20E+02	6.45E+01	1.88E+00	8.86E+02	8.19E+01	MND	MND	3.41E-01	5.09E+01	5.15E-01	9.79E+00	-3.58E+01

EN 15804+A2 disclaimer for Ionizing radiation, human health. This impact category deals mainly with the eventual impact of low dose ionizing radiation on human health of the nuclear fuel cycle. It does not consider effects due to possible nuclear accidents, occupational exposure nor due to radioactive waste disposal in underground facilities. Potential ionizing radiation from the soil, from radon and from some construction materials is also not measured by this indicator.

ENVIRONMENTAL IMPACTS - TRACI 2.1

Impact category	Unit	A1	A2	A3	A1-A3	A4	A5	B1-B7	C1	C2	C3	C4	D
Global warming potential	kg CO2e	9.42E+01	3.88E+00	2.74E+00	1.01E+02	4.92E+00	MND	MND	1.58E+00	3.06E+00	2.39E+00	4.95E-01	-1.22E+01
Ozone depletion	kg CFC11e	4.32E-06	9.51E-07	5.60E-07	5.83E-06	1.21E-06	MND	MND	3.64E-07	7.51E-07	5.51E-07	2.21E-07	-1.02E-06
Photochemical smog formation	kg O3e	2.73E-01	7.49E-03	8.51E-03	2.89E-01	9.51E-03	MND	MND	2.22E-03	5.91E-03	3.36E-03	2.00E-03	-4.52E-02
Acidification	kg SO2e	1.73E-01	3.67E-03	4.42E-03	1.82E-01	4.66E-03	MND	MND	9.67E-04	2.89E-03	1.46E-03	7.40E-04	-6.90E-02
Eutrophication	kg Ne	3.35E+00	7.68E-02	1.50E-01	3.58E+00	9.75E-02	MND	MND	2.24E-02	6.06E-02	3.38E-02	2.90E-02	-5.41E-01
Depletion of non-renewable energy	MJ	3.97E+01	8.62E+00	4.54E+00	5.27E+01	1.08E+01	MND	MND	3.25E+00	6.72E+00	4.92E+00	2.05E+00	-9.02E+00

Fig. 9. Sample EPD generated with One Click LCA EPD generator

Generic LCA data is industry LCA for selected material group. An industry average LCA is the environmental performance of a construction material, calculated as an average across all available manufacturers of a material of a common class.

When selecting building material data for LCA calculations, the principle is always to choose the most appropriate and highest accuracy option (as shown in Fig. 10). Data should be used in the following order of priority.

1. EPD of the product from the specific manufacturer, if available.
2. Technically similar product data from a local manufacturer if the manufacturer is not confirmed yet.
3. Product category level EPD or LCA.
4. Average LCA data for the product in question (same product from different manufacturers)

One Click LCA reviews, verifies, curates, and integrates data from a vast range of public and private sources to the One Click LCA database to give you access to the largest database of environmental construction data in the world (100,000+ data points).

Where can we find LCA data?

LCA data can be obtained from EPD program publishers or a **building LCA database (such as One Click LCA)**. It is essential to have an accurate and robust database to get accurate results and identify the best material alternatives. For example, during the design phase, it helps to compare the environmental performance of building materials before finalizing the design.

LCA data for different project stages

Individual products of any building material type have significant variations in environmental performance, which is reflected in their EPDs. While generic data represents average environmental performance for all products within that category.

During the concept design phase it is best to use generic data, rather than a specific single product EPD, to avoid making design decisions based on the performance of a single product that may not be representative.

EPD data can be used when you are ready to buy the material from a specific supplier. For example, the level of detail required for the construction material steel (Fig.10) increases as the project progresses.

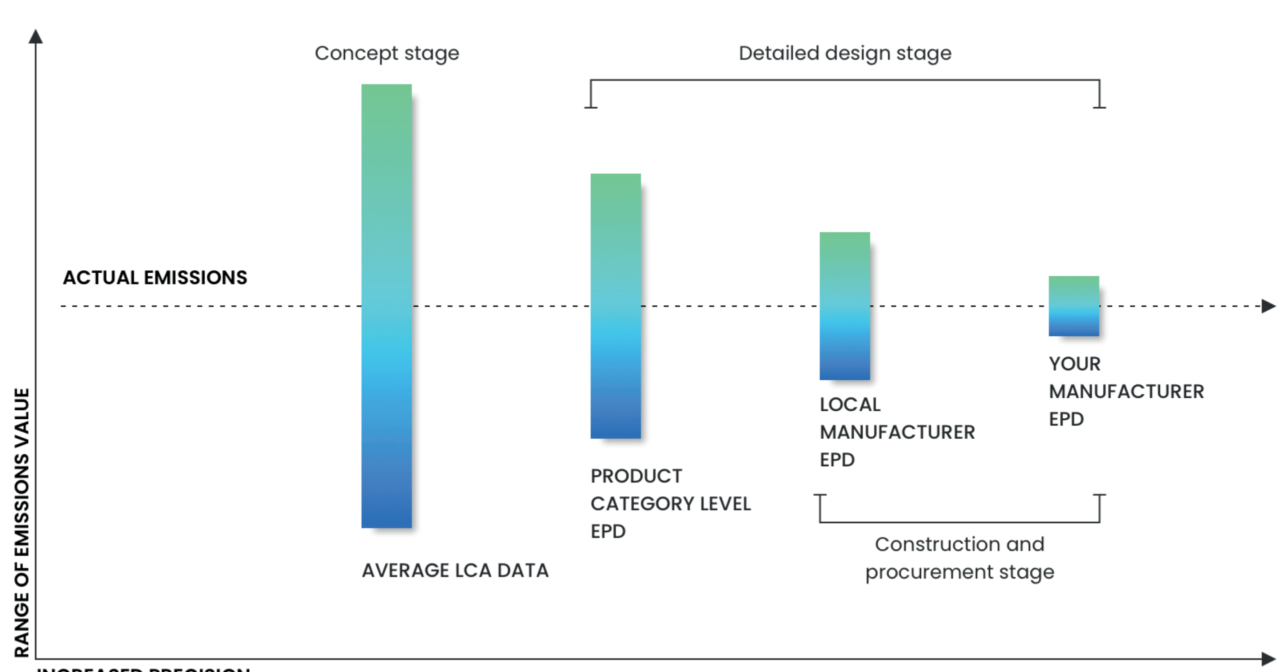


Fig. 10. The use of data depends on the stage of the project

Table 6 summarises the information required for carrying out a building LCA at various project stages.

Table 6. Summary of material quantities and LCA data required for various project stages

Project stage	Material quantities	LCA data	One Click LCA tools or integrations
Concept stage **Advantages in this stage:** » More carbon savings » Very high flexibility » Ability to set targets and make major choices	• Data can be obtained from cost estimation tools or early design tools like Rhinoceros 3D, Tekla Structural Designer • Alternatively, model can be generated with Carbon Designer	• Generic data or using assemblies for building elements (slabs etc.) that contain all the layers and materials. These are available in Carbon Designer • EPDs can be used (if the architects and engineers have decided on the suppliers) **Other options if you do not have ideal data:** • Use material manufacturing localization method	• One Click LCA Carbon Designer • One Click LCA Carbon Heroes Benchmarks
Detailed design stage **Application of LCA in this stage:** » Comparisons between different design alternatives » Carbon benchmarking	• Detailed design drawings or BIM models	• EPD can be used once the materials are finalized. If not, generic data can be used. **Other options if you do not have ideal data:** • Use generic data or EPD that has mid-range performance	• One Click LCA Autodesk Revit, IES, BIM and 15+ integrations
Construction and procurement stage **Purpose of LCA in this stage:** » Detailed LCA for certifications » Comply with regulations	• Construction drawings, BIM models and cost plans of final materials	• Specific supplier EPDs can be used as the suppliers will be finalized **Other options if you do not have ideal data:** • Use private EPDs using private data feature • Model the product yourself • Use most similar data, otherwise	• One Click LCA for buildings • One Click LCA global LCA database • One Click LCA Carbon Heroes Benchmarks

3.3 Step 3: Impact assessment

The overall environmental impact of a building is calculated by performing an Impact assessment. The results are expressed as impact categories (mentioned in Table 1 and others) based on the scope of your LCA. For example, the Level(s) assessment requires you to report GWP, AP, EP, ODP, POCP, and biogenic carbon.

Impact assessment is carried out by multiplying the life-cycle inventory (LCI) with the appropriate impacts for each material or process during the life-cycle impact assessment step (Fig. 11). The environmental profile of the inventory is obtained from the respective EPDs or generic data.

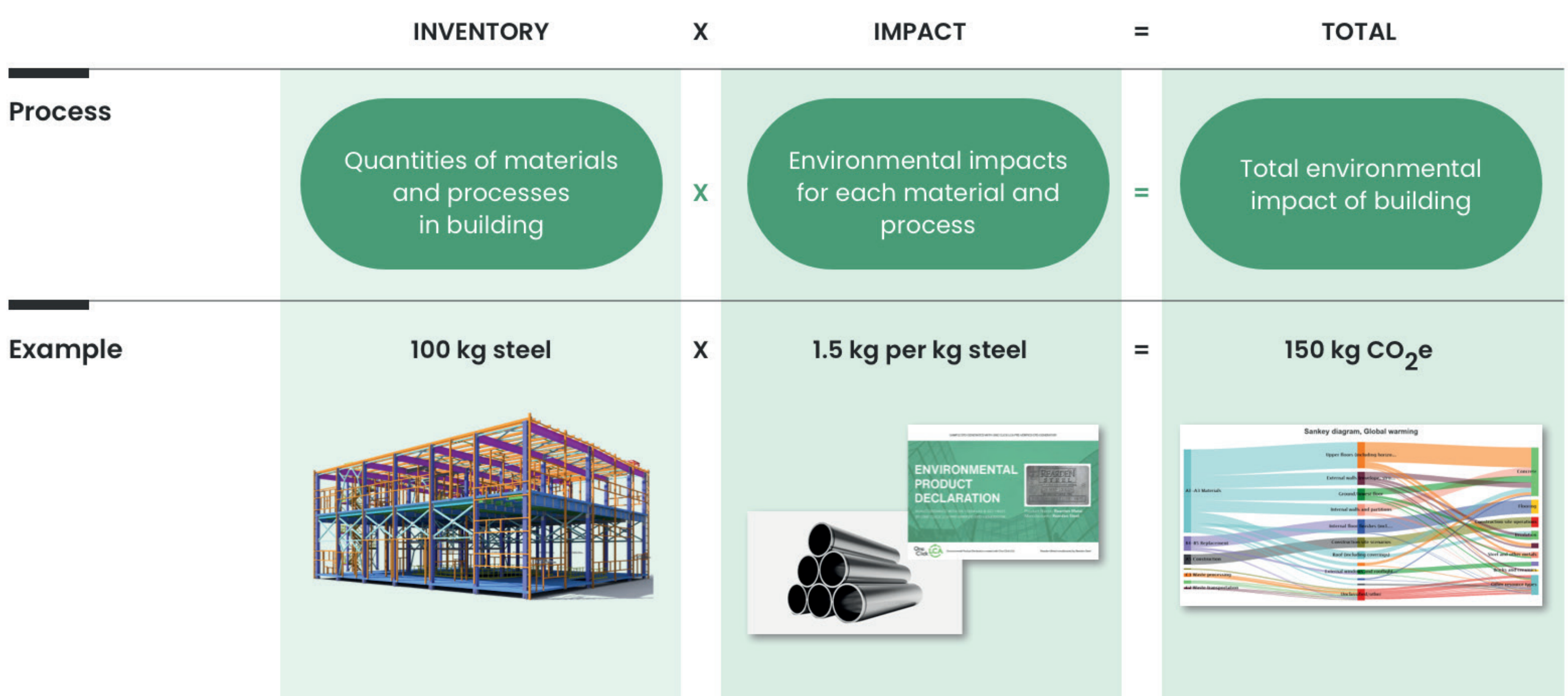


Fig. 11. Example of impact assessment calculations

One Click LCA fully automates the calculations of impacts from building materials, scenarios and gives results by life-cycle stage and building component.

3.4 Step 4: Results and analysis

Once you have the building LCA results, it is useful to break down the environmental impacts by building component, material type, and life-cycle stages and then visualize the results. This helps to identify hotspots and reduce impacts where it matters most.

After conducting a building LCA analysis, you must verify the completeness and plausibility of your data to ensure it complies with your required scope.

The process can be simplified using the LCA Checker feature in One Click LCA. It indicates the completeness of the project and identifies weak areas in the analysis.

3.5 Visualizing Building LCA

By performing a building LCA, you can identify and analyze the environmental impacts distributed across life-cycle stage, materials, and structural elements. Once the environmental impacts and hotspots have been identified, you can optimise your designs and make informed decisions to lower the impacts of your project.

To understand how this works in practice, we will look at the results of an example building LCA project carried out according to the EN 15978 standard using One Click LCA software.

1. Impacts from life-cycle stages

Fig 12. illustrates how GWP is distributed among the different life-cycle stages of a building. The results imply that efforts must be focused on the product stage of the building to reduce the GWP.

Other environmental impacts measured per life-cycle stage are shown below (Fig.13). Construction materials (product stage) contribute to most of the impacts irrespective of the environmental impact category.

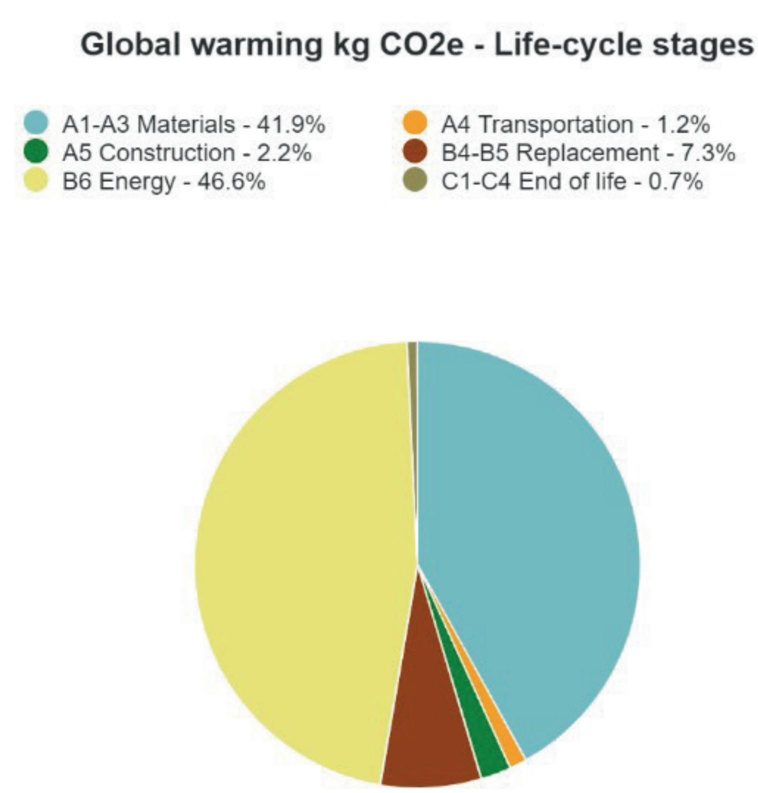


Fig. 12. Distribution of GWP across different life-cycle stages

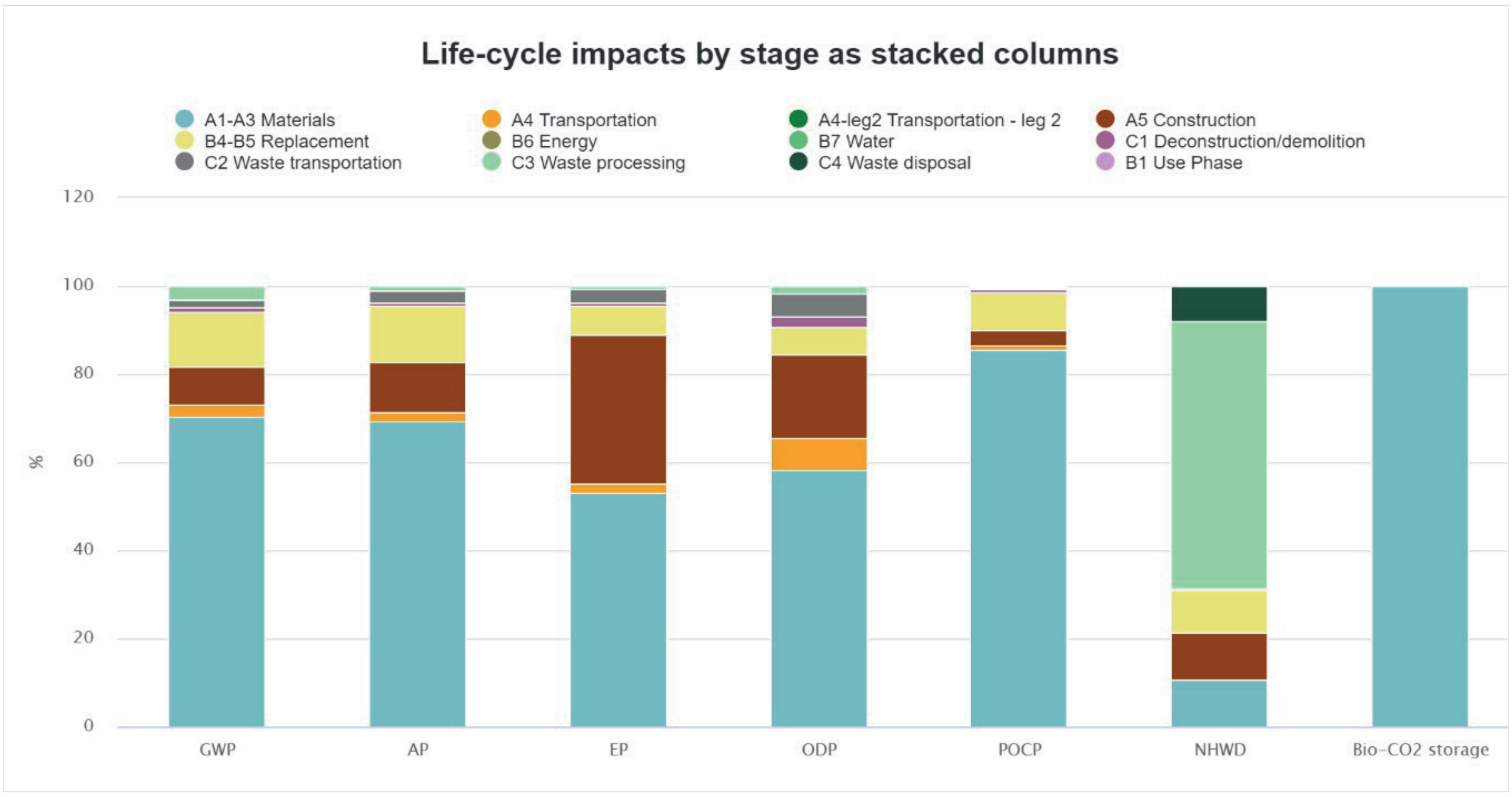


Fig. 13. Distribution of environmental impacts across different life-cycle stages

2. Impacts from building materials

Building materials are significant sources of emissions. Carbon emissions released before using a building (**upfront carbon**) are of great concern as they are irrevocably released before construction. In the building LCA results below, concrete, steel, insulation and carpeting are shown as materials with high environmental impact (Fig.14).

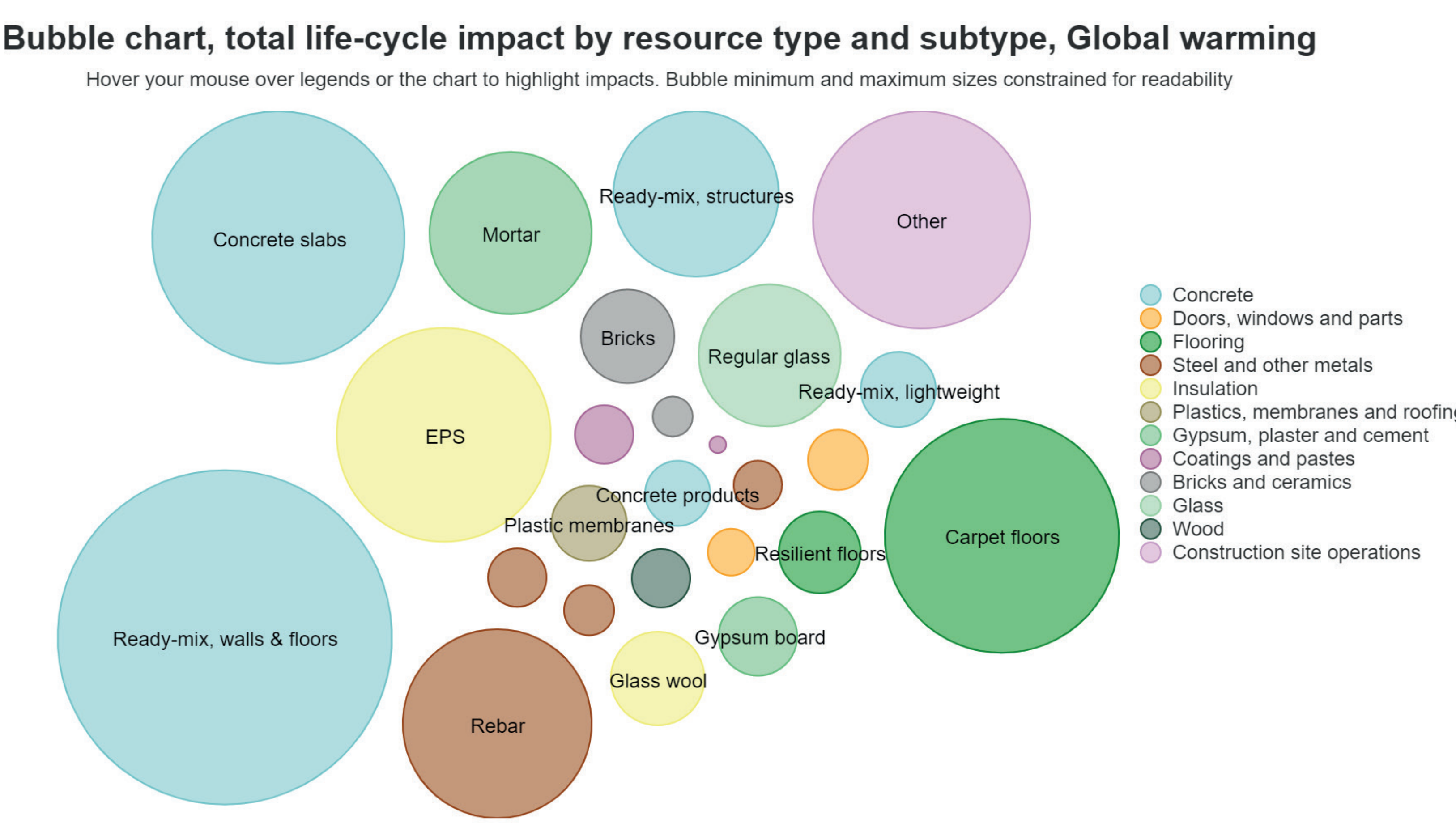
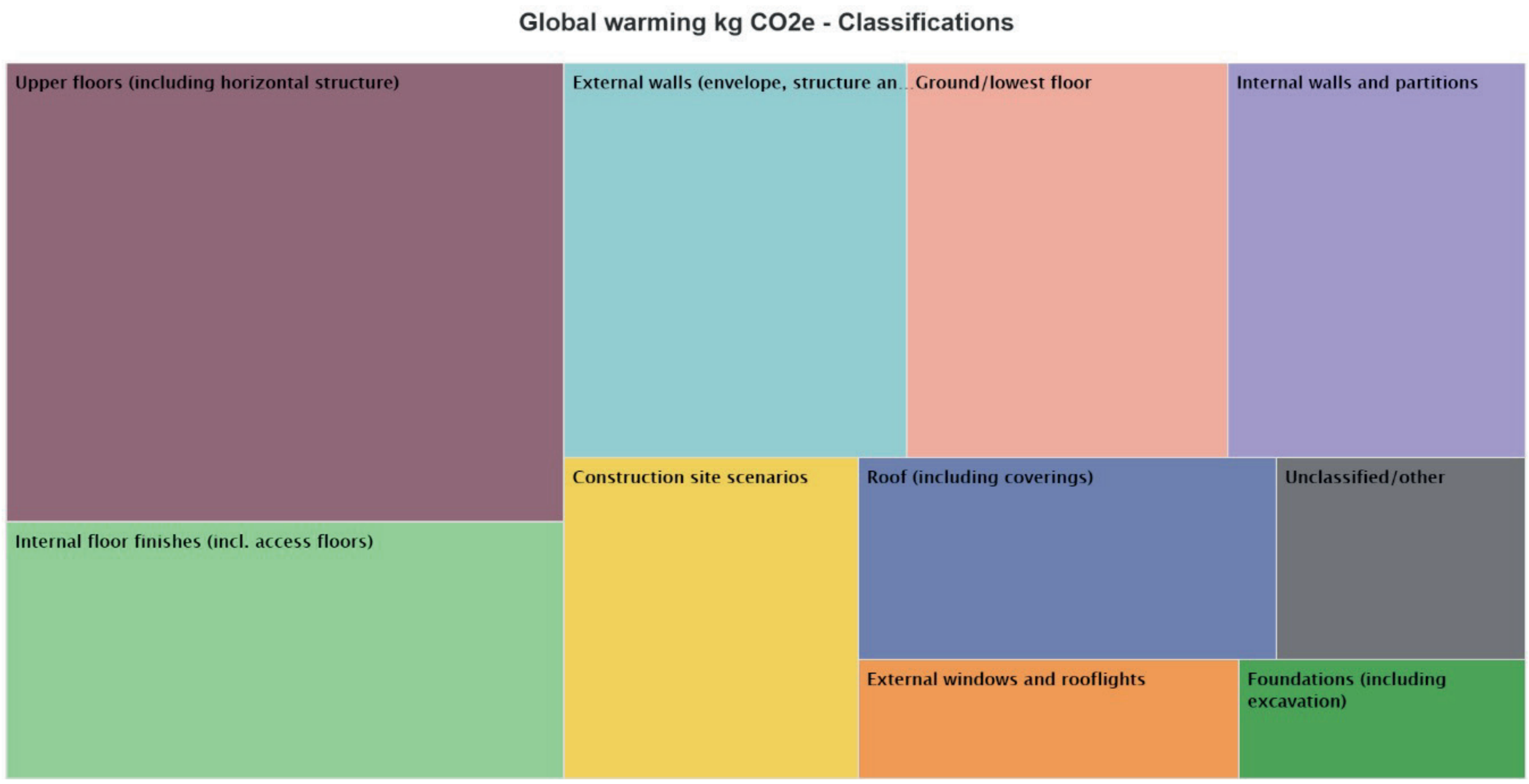


Fig. 14. Embodied carbon hotspots of a project shown as bubble chart (surface of bubble correlates with climate impact relative to each other)

3. Impacts from building elements

A Building LCA also identifies which building elements are significant environmental concerns. For example, the results shown below indicate that the upper floors are the major contributor to global warming (Fig.15).



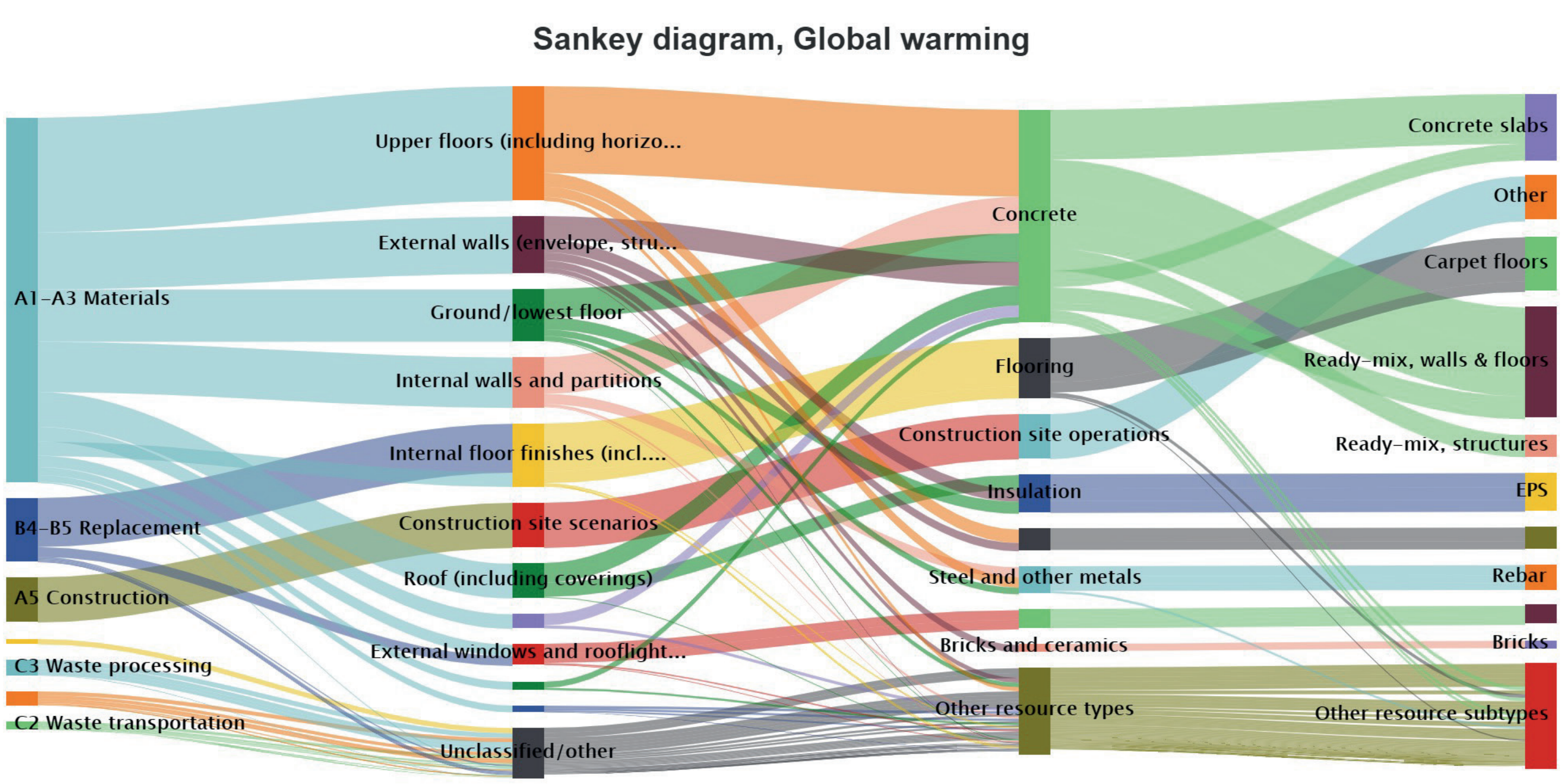


Fig.15. Embodied carbon breakdown by key building elements (Treemap and Sankey diagram)

4. Design optioneering

Comparing the impacts of different design alternatives is helpful for decision-making. For example, the same building constructed with concrete, steel, or wood will differ in environmental impact, as shown below (Fig.16).

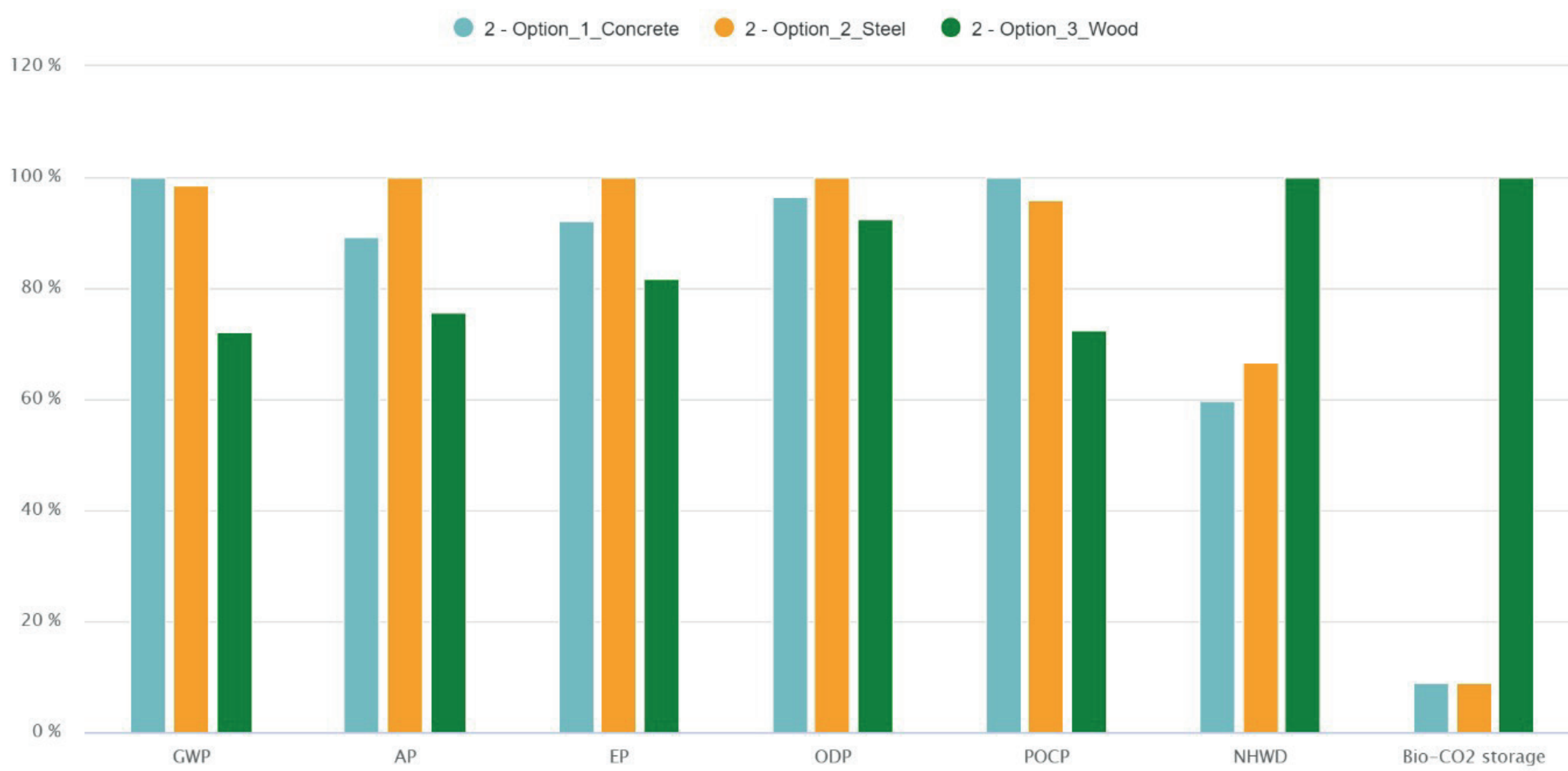


Fig.16. Design optioneering can help in reducing emissions

5. Benchmarking your project

The Carbon Heroes Benchmarks feature in One Click LCA can benchmark your project's embodied carbon with thousands of buildings across different countries (Fig. 17).

Our research on Embodied Carbon Benchmarks for European buildings provides benchmark data for European buildings including Northern Europe, Western Europe and Eastern Europe.

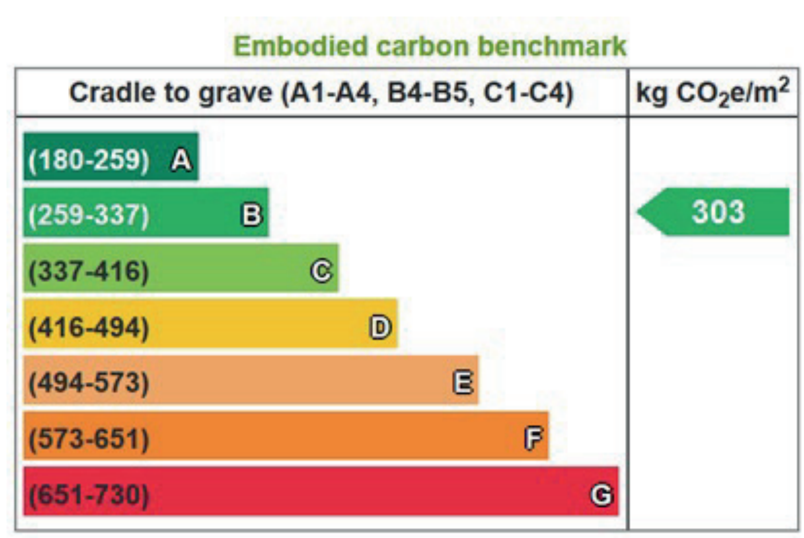


Fig. 17. One Click LCA Carbon Heroes Benchmarks

4. HOW TO DECARBONIZE PROJECTS?

4.1 Decarbonization: the role of various stakeholders

Alignment and collaboration between various stakeholders in the construction industry is crucial to decarbonization since no stakeholder can achieve this alone. The following diagram (Fig. 18) suggests measures to reduce embodied carbon at each project stage.

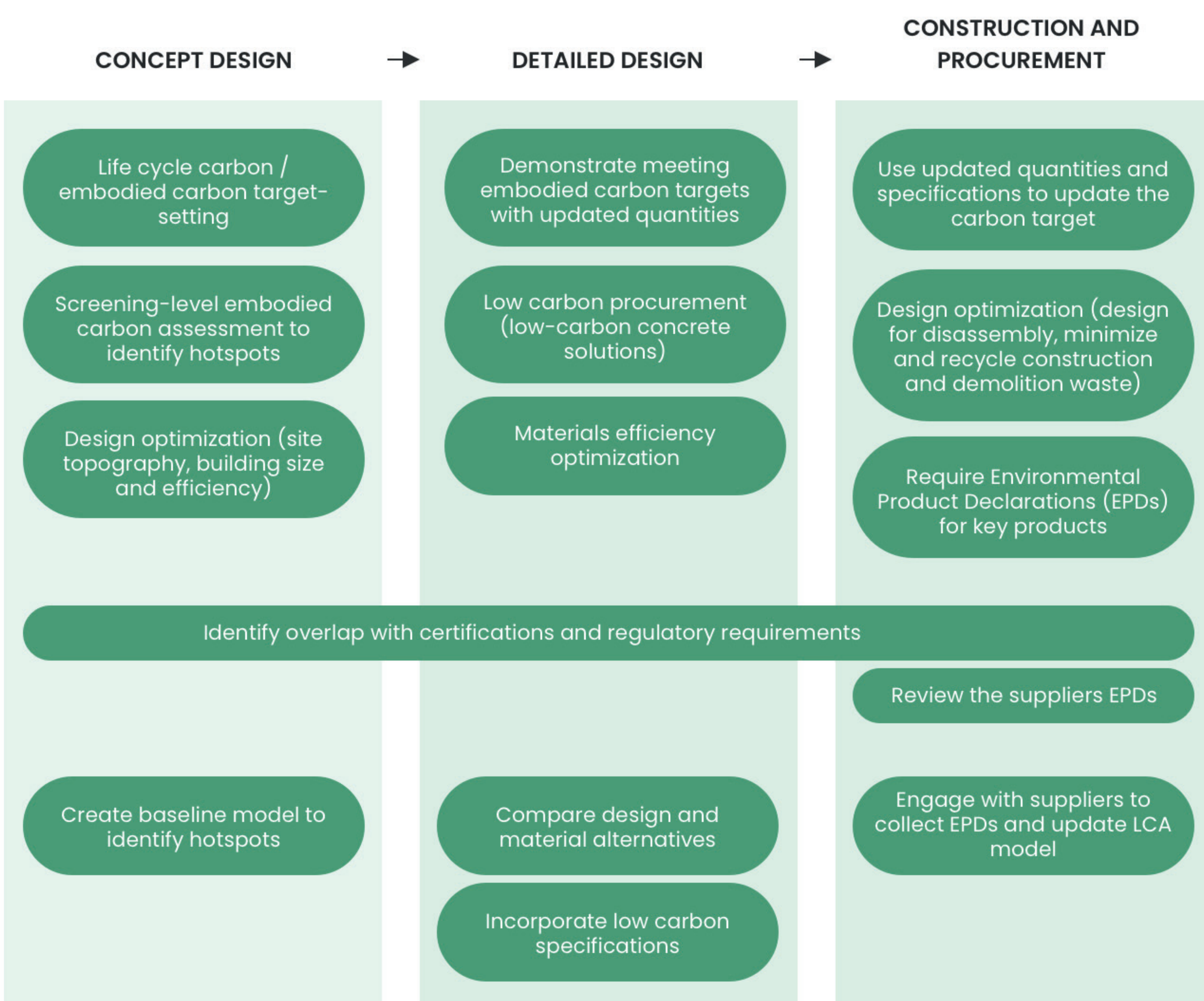


Fig. 18. Measures to reduce embodied carbon at each project stage

The following table (Table 7) describes how various stakeholders can help in decarbonizing the construction sector. Since consultants support the entire supply chain with their decarbonization services and solutions, they are not mentioned as a separate category in the table.

Table 7. How can various stakeholders help in decarbonizing the construction sector

Designers

What can they do?

1. Conduct WBLCA to identify hotspots
2. Compare material options
3. Conduct screening level LCA to identify hotspots

Why?

- Differentiate their services and deliver better design
- Justify sustainable design choices (to clients) with scientific evidence

How?

- Compare whole life-cycle impact of any materials
- Compare different designs and geometries
- Parametric LCA optimisation
- Screening level LCA to identify hotspots

Tools

- One Click LCA Carbon Designer
- One Click LCA integrations (Autodesk Revit, IES, BIM)

Investors

What can they do?

1. Set benchmarks for carbon impacts
2. Collect Scope 3 emissions data from all projects
3. Prepare embodied carbon policy

Why?

- Transparency, managing risk and benchmarking their portfolio

How?

- Set benchmark levels for the carbon impacts of projects
- Prepare a carbon policy for projects

Tools

- One Click LCA Carbon Designer
- Carbon Heroes Benchmarks
- Building LCA, LCC

Manufacturers

What can they do?

1. Measure, benchmark and ultimately reduce the impact of their products.
2. Sustainable product design

Why?

- Reduce energy costs
- Increase differentiation

How?

- Promote sustainable solutions
- Comparative product benchmarking

Tools

- Building and product LCA tools
- One Click LCA EPD Generator

Builders and developers

What can they do?

1. Review concept design stage embodied carbon target setting
2. Create carbon baseline
3. Compare design alternatives
4. Evaluate circularity of materials and design options
5. Investigate prefabrication opportunities

Why?

- Build projects that are net zero, reducing cost and increasing material efficiency.
- Decrease material buying and installation cost
- Decrease waste handling cost

How?

- Screen the site selection using carbon metrics
- Reduce impact from materials using sustainable alternatives
- Conduct circularity assessment of the project

Tools

- One Click LCA Carbon Designer
- One Click LCA Net Zero

4.2 How One Click LCA can help

One Click LCA is the world-leading life-cycle assessment (LCA) and Environmental Product Declaration (EPD) generation software for the construction industry. A low carbon construction one-stop-shop, One Click LCA provides solutions for construction projects, products and portfolios. It is used in more than 120 countries, includes the world's largest construction sector database, and supports over 60 standards and certifications. For more information, visit One Click LCA.

Here are some reasons to choose One Click LCA for performing building LCA.

1. **Ease-of-use:** It is an easy web-based tool for life-cycle assessment, life-cycle costing, and more.
2. **Get reliable whole building LCA, instantly:** Automate LCA with BIM and BEM integrations.
3. **Compliancy:** Supports EN/ISO standards and complies with BREEAM, LEED, DGNB, and 60+ other certification schemes, standards, and requirements.
4. **World's largest environmental construction database:** One Click LCA's database has over 100k data points, including existing market EPDs, available for you to use.
5. **Outstanding support from our experts:** As well as providing technical support on our software, our team's deep knowledge of the sector enables them to support issues like certification and regulation requirements.

Table 8. One Click LCA Building LCA subscription plans

Plan	Starter	Business	Expert
Summary	Easy to use tool for project carbon and LCA work	Automated LCA for scaling up your business	Advanced LCA and eco-design and customisation
Who is it for?	For businesses looking for an easy and robust way to calculate embodied carbon and LCA for their clients and to compare different designs.	For designers and others looking to automate LCA with BIM and other data sources, with quick optioneering tools and robust quality control.	For businesses requiring advanced LCA modelling capability and private LCIA data or construction libraries, and extensive benchmarking.
Business benefits	» Calculate embodied carbon & LCA » Comprehensive generic data and global EPDs » Compare design alternatives » Visualize results with built-in graphs » Outstanding customer support	» Includes everything from Starter and also: » Import from BIM, BEM, Excel » BIM Model Checker » LCA Checker » Carbon Heroes Benchmarking » Download EPDs directly » 1.5 hour online training included	» Includes everything from Business and also: » Compare any products for carbon and cost » Customise data input with private assemblies and recipes » Allow others to send you data directly from BIM » Advanced LCA modeling » Extensive graphs and visuals » Advanced online training included

Add-ons

- **Carbon Designer:** helps you to quickly generate and compare different design options by using predefined building structures or materials.
- **Net Zero Carbon**: helps you to quantify all carbon-emitting and carbon-reducing options in their projects to comply with local Net Zero Carbon definitions.
- **Building Circularity:** helps you to Incorporate the principles of circular economy into your building designs.
- **Site Designer**: helps you to calculate and compare the carbon impacts of different sites, energy supplies and transport scenarios, enabling you to make carbon-informed choices at the earliest stage of your project.
- **Compliance tools**: for certifications such as BREEAM, LEED, etc.
- **Life Cycle Costing:** helps you choose the most eco-friendly and cost-efficient design.
- **Interior Design Carbon:** helps you quantify and reduce carbon impacts for interior fit-outs, tenant improvement and refurbishment projects

APPENDIX

Standards governing building LCA

Building LCA is performed according to international standards **(ISO 14040, 14044, or EN 15978).** These standards (Table 8) ensure transparency and consistency, meaning that the results obtained from an LCA are robust and widely respected.

Table 9. Standards governing building LCA

Cornerstone standards	Construction works specific standards	EPD standards
ISO 14040 (fundamentals for LCA)	EN 15978 – LCA standard for construction projects (European standard, basis for all EU regulations)	ISO 14025 – cornerstone standard for all kinds of EPDs
ISO 14044 (fundamentals for LCA)	ISO 21929-1 and ISO 21931-1 (less used LCA standards)	EN 15804 (EPD data) and EN 15942 (EPD format) (European standard, basis for all EU regulations) ISO 21930

Background on Life Cycle Impact Assessment

In LCA, the LCI is converted into environmental impacts using a **characterisation model**. For instance, methane is one component that impacts the GWP (Global Warming Potential) impact category. Thus, it is transformed into CO_2 equivalents (Co_2e) using a characterisation method (CML, TRACI and EN 15804+A2).

For tools targeting European markets, the prevailing impact assessment methodology is **CML –IA 2012**, which was created by the University of Leiden in 2001. North American markets use **TRACI,** short for 'Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts', which was developed by the U.S. Environmental Protection Agency. For the European region, a PEF-aligned characterisation as used in EN 15804:2019 +A2 can be expected to become more popular over coming years.

The **EN 15804+A1** reports seven impact categories, two of which represent resource depletion and 17 reporting categories for resource use, waste generation, and output flow data. In **EN 15804+A2**, the climate impact category is split into four different reported categories. The previous single Global Warming Potential category is no longer provided. The difference in mandatory environmental impact categories in A1 and A2 standards are shown in Fig.19.

ENVIRONMENTAL IMPACT DATA

ENVIRONMENTAL IMPACTS - EN 15804+A1, CML

Impact category	Unit	A1	A2	A3	A1-A3	A4	A5	B1-B7	C1	C2	C3	C4	D
Global warming potential	kg CO2e	6,26E1	3,92E0	4,1E0	7,06E1	4,97E0	MND	MND	1,6E0	3,09E0	2,42E0	5,07E−1	−1,28E1
Depletion of stratospheric ozone	kg CFC11e	1,54E−6	7,15E−7	4,92E−7	2,75E−6	9,07E−7	MND	MND	2,73E−7	5,64E−7	4,13E−7	1,65E−7	−7,56E−7
Photochemical ozone formation	kg C2H4e	8,04E−3	5,16E−4	1,03E−3	9,59E−3	6,55E−4	MND	MND	2,43E−4	4,07E−4	3,67E−4	1,47E−4	−6,71E−3
Acidification	kg SO2e	1,24E−1	7,98E−3	2,04E−2	1,52E−1	1,01E−2	MND	MND	2,36E−3	6,3E−3	3,57E−3	2,01E−3	−4,68E−2
Eutrophication	kg PO4 3e	3,57E−2	1,66E−3	4,32E−3	4,17E−2	2,11E−3	MND	MND	4,16E−4	1,31E−3	6,28E−4	3,88E−4	−2,71E−2
Abiotic depletion of non-fossil	kg Sbe	2,3E−5	9,78E−5	9,21E−6	1,3E−4	1,24E−4	MND	MND	2,44E−6	7,71E−5	3,69E−6	4,63E−6	−4,29E−4
Abiotic depletion of fossil	MJ	2,07E2	5,91E1	4,43E1	3,11E2	7,5E1	MND	MND	2,17E1	4,66E1	3,29E1	1,41E1	−1,78E2

MND abbreviation stands for Module Not Declared

CORE ENVIRONMENTAL IMPACT INDICATORS – EN 15804+A2, PEF

Impact category	Unit	A1	A2	A3	A1-A3	A4	A5	B1-B7	C1	C2	C3	C4	D
Climate change – total	kg CO2e	9.75E+01	3.90E+00	5.13E+00	1.06E+02	4.96E+00	MND	MND	1.59E+00	3.08E+00	2.40E+00	5.01E-01	-1.26E+01
Climate change – fossil	kg CO2e	9.65E+01	3.88E+00	2.73E+00	1.03E+02	4.93E+00	MND	MND	1.59E+00	3.06E+00	2.40E+00	4.98E-01	-1.24E+01
Climate change – biogenic	kg CO2e	9.39E-01	2.31E-02	2.39E+00	3.35E+00	2.93E-02	MND	MND	2.69E-03	1.82E-02	4.06E-03	3.16E-03	-2.27E-01
Climate change – LULUC	kg CO2e	1.95E-02	1.38E-03	1.45E-02	3.53E-02	1.75E-03	MND	MND	1.35E-04	1.09E-03	2.04E-04	1.51E-04	-9.13E-03
Ozone depletion	kg CFC11e	3.85E-06	8.98E-07	4.31E-07	5.18E-06	1.14E-06	MND	MND	3.45E-07	7.08E-07	5.22E-07	2.09E-07	-8.42E-07
Acidification	mol H+e	3.31E-01	9.18E-03	9.97E-03	3.51E-01	1.17E-02	MND	MND	2.73E-03	7.24E-03	4.13E-03	2.39E-03	-5.42E-02
Eutrophication, aquatic freshwater	kg PO4e	2.11E-02	2.98E-04	5.22E-04	2.19E-02	3.79E-04	MND	MND	5.80E-05	2.35E-04	8.77E-05	5.25E-05	-7.16E-03
Eutrophication, aquatic marine	kg Ne	5.77E-02	1.29E-03	2.58E-03	6.15E-02	1.63E-03	MND	MND	3.68E-04	1.01E-03	5.56E-04	4.69E-04	-1.04E-02
Eutrophication, terrestrial	mol Ne	6.59E-01	1.37E-02	2.86E-02	7.02E-01	1.73E-02	MND	MND	3.93E-03	1.08E-02	5.95E-03	5.09E-03	-1.06E-01
Photochemical ozone formation	kg NMVOCe	1.89E-01	7.09E-03	8.27E-03	2.05E-01	9.01E-03	MND	MND	3.91E-03	5.60E-03	5.92E-03	2.09E-03	-4.32E-02
Abiotic depletion, minerals & metals	kg Sbe	5.69E-04	9.78E-05	1.01E-05	6.76E-04	1.24E-04	MND	MND	2.44E-06	7.71E-05	3.69E-06	4.63E-06	-4.29E-04
Abiotic depletion of fossil resources	MJ	7.13E+02	5.91E+01	4.16E+01	8.14E+02	7.50E+01	MND	MND	2.17E+01	4.66E+01	3.29E+01	1.41E+01	-1.78E+02
Water use	m3e depr.	1.88E+03	9.25E+01	2.02E+03	3.99E+03	1.17E+02	MND	MND	1.23E+01	7.30E+01	1.86E+01	1.25E+01	-7.98E+02

EN 15804+A2 disclaimer for Abiotic depletion and Water use indicators and all optional indicators except Particulate matter and Ionizing radiation, human health. The results of these environmental impact indicators shall be used with care as the uncertainties on these results are high or as there is limited experienced with the indicator.

7

Environmental Product Declaration created with One Click LCA   Rearden Metal manufactured by Rearden Steel

Fig. 19. The difference in mandatory environmental impact categories in A1 and A2 standards

Normalization and weighting (optional)

Normalization followed by weighting is generally used to produce a single numerical score by weighting each impact category and summing them up into a single score. Normalization aims to understand the relative magnitude for each indicator result of the product under study. One Click LCA uses this method only for Eco Points or the Dutch MPG method, which uses specific rules for normalization provided by BRE.

REFERENCES

1. The Paris Agreement
2. UN Sustainable Development Goals
3. Unregulated energy use and carbon emissions from buildings – and how it is changing
4. Compliancy and Certifications
5. Energie Carbone (E+C-)
6. Building area
7. How we work with data
8. Carbon Heroes Benchmarks