How to calculate the embodied carbon of facades: A methodology

Issue 1, September 2022

This document was written by the Centre for Window and Cladding Technology Embodied Carbon Committee under the guidance of the Sustainability Committee.

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Foreword

Embodied carbon is defined by the UK Green Building Council as the 'total greenhouse gas emissions generated to produce a built asset. This includes emissions caused by extraction, manufacture/processing, transportation and assembly of every product and element in an asset and may also include maintenance, replacement, deconstruction, disposal and end-of-life' (UK GBC, 2017).

This sounds quite simple, but in reality, it is anything but straightforward and the complexity associated with calculating the embodied carbon of facade systems should not be underestimated.

With the emphasis in recent decades on reducing the operational carbon emissions from buildings, embodied carbon is becoming more significant, and there is an increasing shift in focus towards embodied carbon assessment. This now requires more detailed quantification to better understand emissions and how they can be most effectively reduced. This is key as we move towards 'net-zero' buildings.

With no previous agreed specific guidance, it was quickly identified by the CWCT that a consistent methodology for calculating the embodied carbon of facade systems was vital if we wanted to better understand the contribution that our facades make, be able to compare different options, quantify improvements and set targets.

The CWCT believes that this is the first detailed methodology specifically for facades, and we think that this is a really important document. It is recognised however that there remain areas of uncertainty, where further information is required to better understand the embodied carbon associated with different life-cycle stages. We are therefore relying on feedback from users to help tell us about the challenges faced applying the methodology, to inform us of developments in this field, and so on. This feedback is crucial, and it is intended to update the methodology as further information becomes available and experience in carrying out these assessments increases.

This methodology was widely peer reviewed prior to publication, and the review process provided valuable feedback. We would like to thank all those who participated in this important stage. We hope that this engagement will also help to increase industry acceptance of this methodology, in order to provide much-needed consistency.

Whilst this methodology is a key first step, it is not the end of the journey. What really matters is the whole-life carbon emissions of a building, and this introduces further complexities, due to the interdependencies between the building structure, facade and building services for example. These elements should not be considered in isolation, and we aim to provide further guidance on this in the future.

If you have any comments on the methodology, please email sustainability@cwct.co.uk.

John Downes, Chair, CWCT Sustainability Committee
David Metcalfe, Director, CWCT.

Introduction

This document is focused on the Global Warming Potential (GWP) environmental impact indicator identified in BS EN 15804 and alignment with whole life carbon assessment documents produced by other construction industry bodies referenced in this document. The CWCT acknowledge that life cycle assessments (LCA) have a much wider remit than GWP alone, and that LCAs also consider other environmental impact indicators as set out in Tables 3 and 4 of BS EN 15804. Additionally, legislation such as the Environment Act 2021 must be considered when designing and constructing the building envelope. It is intended that further guidance related to assessing additional environmental indicators, including interpretation of new and updated legislation that becomes available will be addressed in later publications from the CWCT.

While writing this document, the CWCT have recognised that there are various limitations as well as important future tasks that must be carried out to update this document in the future to reflect the latest knowledge and experience on this subject. This future work will also aim to provide more useful guidance to users of this document.

At this time, the following items anticipated as future work include:

- Reference values for a range of carbon calculation scale-up factors that can be applied to address different types of uncertainties in assessments;
- Further guidance on the assessment approach to module D, which will be in coordination with the CWCT's EPD Workstream guidance;
- Additional product specific guidance for selecting embodied carbon factors for use during early design stages and in the absence of project specific data. This will be similar to the glazing methodology appendix included within this document;
- Additional emission factors identified as necessary for assessments. And as more data becomes available, refinement of existing factors including methodologies for users to derive different factors;
- Reference facade specific embodied carbon factors from open-source databases;
- Guidance dedicated to assessing existing facade systems.

These items have also been highlighted throughout the document where relevant at this stage. The CWCT welcome continued feedback from industry on the development of this document in the future.

A Worked Example for a facade LCA assessment following the guidance in this document will be provided by the CWCT as a separate document. Please refer to the website to access this document.

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Abbreviations and terms

The following abbreviations are used within this document.

BIM	Building Information Modelling
CIBSE	Chartered Institution of Building Services Engineers
CWCT	Centre for Window and Cladding Technology
ECF	Embodied Carbon Factor
EPD	Environmental Product Declaration
FSA	Facade Surface Area
GIA	Gross Internal Area
GWP	Global Warming Potential
IStructE	Institution of Structural Engineers
IGU	Insulating Glass Unit
LCA	Life Cycle Assessment
RIBA	Royal Institute of British Architects
RICS	Royal Institution of Chartered Surveyors
RSL	Reference Service Life
RSP	Reference Study Period
SFS	Structural Framing System

The following terms are used within the equations presented in this document.

$\boldsymbol{A}$	Representative facade surface area under assessment (m^2)
$\boldsymbol{A_g}$	Glazed surface area (m^2) within representative area assessed
$\boldsymbol{A_{total}}$	Total facade surface area on the building (m^2)
$\boldsymbol{CAEF}$	Construction activities emissions factor for a whole building ($kgCO_2e$/£100,000 of Project Cost)
$\boldsymbol{CL_i}$	Component lifespan (years)
$\boldsymbol{CR}$	Cleaning rate (i.e. the number of times the glazing is cleaned each year) (cleans/year)
$\boldsymbol{EC_M}$	Embodied carbon for module *M* ($kgCO_2e$). Note: '*M*' is a generic placeholder to indicate a reference to life cycle modules the factor considers (for example: EC_{A13}, EC_{A15}, EC_{AC}, EC_D etc.).
$\boldsymbol{ECF_{M,i}}$	Embodied carbon factor for module *M* and i^{th} material ($kgCO_2e/kg$) Note: '*M*' is a generic placeholder to indicate a reference to the life cycle modules the factor considers (for example: $ECF_{A13,i}$, $ECF_{A4,i}$, $ECF_{C34,i}$, $EC_{D,i}$ etc.).
$\boldsymbol{F}$	Carbon calculation scale-up factor (section 2.2.15)
$\boldsymbol{F_{clean}}$	Glazing cleaning emissions factor ($kgCO_2e/m^2$ glazing)
$\boldsymbol{FC}$	Fuel consumption (kWh or litre)
$\boldsymbol{FC_{\%}}$	Facade cost as a percentage of the project cost (%). Advice should be sought from the project Quantity Surveyor at an early stage
$\boldsymbol{FCF_s}$	Fuel carbon factor for fuel source 's' ($kgCO_2e$/kWh or $kgCO_2e$/litre)
$\boldsymbol{FEI}$	Factory energy intensity (kWh/m^2 of facade system)
$\boldsymbol{FFF}$	Facade Form Factor (no units)
$\boldsymbol{FSA}$	Facade Surface Area (m^2)
$\boldsymbol{GCF}$	Grid carbon factor ($kgCO_2e$/kWh)
$\boldsymbol{i^{th}}$	The term "i^{th}" is used as a generic reference to identify the instance of any single component or material within a list of components from 0 to n. (i.e. 1^{st} component, 2^{nd} component, 3^{rd} component, … i^{th} component, … n^{th} component).
$\boldsymbol{PC}$	Project capital cost (£).
$\boldsymbol{Q_i}$	Quantity of i^{th} material or component (kg)
$\boldsymbol{RSP}$	Reference Study Period (years) refer to section 2.2.8 for further details.
$\boldsymbol{TD_{mode}}$	Transport distance for given mode of transport (km)
$\boldsymbol{TEF_{mode}}$	Transport emissions factor for given mode of transport (gCO_2e/kg.km)
$\boldsymbol{WF_i}$	Waste factor for i^{th} material (%)
$\boldsymbol{WR_i}$	Wastage rate for i^{th} material (%)

Terminology

Key terminology used within this guide is presented below. For further guidance on the common terms and phrases associated with the field of sustainability readers are referred to the CWCT's *Climate Jargon Buster* (7).

Biogenic carbon
Biogenic carbon refers to carbon removal associated with carbon sequestration into biomass as well as any emissions associated with this sequestered carbon.

Carbon equivalent
Carbon equivalent, often informally simplified to "carbon", is the unit of measurement of the Global Warming Potential (GWP) environmental indicator as recognised in Table 2 of BS EN 15978 (1). Carbon equivalent is measured in units of $kgCO_2e$ or $kgCO_2$-equiv.

Embodied carbon factor
An Embodied Carbon Factor (ECF), often informally shortened to 'carbon factor', refers to the GWP of a given quantity of a product or material. Any definition of an ECF should make clear the product and life cycle modules to which it accounts.

End of Life (EoL)
The End of Life (EoL) stage of a building starts when the building is decommissioned and is not intended to have any further use. The EoL stage includes the emissions associated with the deconstruction (C1), transport away from site (C2) and end-of-life scenarios (C3 – C4).

Where materials and components are designed to be replaced during the life of the building, the EoL stage, and associated emissions, of these materials and components will occur chronologically earlier than that of building as a whole. These emissions are accountable to module B4.

Fabrication, Assembly, and Installation
Designers should note that within the scope of this guide terms 'fabrication', 'assembly' and 'installation' are distinguished as follows:

- 'Fabrication' refers to the processing and forming of a component(s). For this reason, the embodied carbon factor $ECF_{A3,FAB}$ is applied at the component level;
- 'Assembly' refers to the assemblage of components into a facade system. These works, and associated emissions, may occur on and off the project site to a varying degree. The embodied carbon factor $ECF_{A3,ASS}$ is applied at the facade system level;
- 'Installation' refers to the works undertaken to the facade on the project site during the construction and for many facade systems is likely to include a degree of 'assembly'.

Facade Form Factor
The Facade Form Factor (FFF) is used to express the ratio of the Facade Surface Area (FSA) to the Gross Internal Floor area (GIA).

Facade Surface Area (FSA)
The Facade Surface Area (FSA) refers to the surface area of the building envelope considered within the scope of the embodied carbon assessment. Note, this may/may not include horizontal surfaces of roofs, terraces and soffits. When assessing the FSA, it is recommended to exclude all projections that occur outside of the thermal line (e.g. feature fins, external balconies and other attachments) from the assessment of the surface area.

Facade system
An assembly of materials and components that delivers a prescribed functional performance to the building envelope. A building may consist of one or more facade systems.

Functional equivalent
The functional equivalent is the documented quantified functional requirements and/or technical

requirements for a facade system for the use as a basis of comparison. Further guidance on presenting the functional equivalent is given in section 2.4.2.

[Adapted from BS EN 15978:2011]

Gross Internal Area (GIA)
The Gross Internal Area (GIA) is the plan internal area of a building measured to the internal face of the perimeter walls at each floor level.

Global Warming Potential (GWP)
Global Warming Potential (GWP) is a measure of how much energy the emissions of 1 ton of a gas will absorb over a given period of time, relative to the emissions of 1 ton of carbon dioxide (CO_2) (i.e. The GWP of CO_2 is 1 kgCO_2e/kg). The GWP is measured in kgCO_2e (referred to 'carbon equivalent'). The GWP measure was developed to allow comparisons of the global warming impacts of different greenhouse gases (2). The GWP of construction products are reported within EPDs.

Materials and components
The term 'materials and components' is used within this document to refer to the elements that form a facade system. These elements may include monolithic materials and fabricated components. To this extent a facade system may be thought of as an assembly of materials and components.

Reference study period (RSP)
The Reference Study Period (RSP) is the period of time over which the time-dependent characteristics of the object of assessment are analysed.

[Adapted from BS EN 15978:2011]

Reference service life (RSL)
The Reference Service Life (RSL) is the service life of a product, component, assembly or system which is known to be expected under a particular set, i.e. a reference set, of in-use conditions and which can form the basis for estimating the service life under other in-use conditions.

[BS ISO 15686-1:2011]

Sequestration
Carbon sequestration can be defined as the capture and long-term secure storage of carbon from the atmosphere. Biogenic carbon is a type of sequestration. Common sequestration mechanisms relevant to the facade industry include the photosynthesis of plants and carbonation of concrete.

1. Preliminaries

In June 2019, the UK parliament passed legislation requiring the government to reduce the UK's net emissions of greenhouse gases by 100% relative to a 1990s baseline by 2050 (3). The UK government has set legally-binding 'carbon budgets' to guide this transition, these budgets include reducing emissions by 78% by 2035 (4).

The UK facade and cladding industry have a responsibility to support this transition. Reducing the whole-life carbon of facade and cladding systems is a key part of this transition. Such reductions require accurate and comparable assessments of embodied carbon.

1.1. Aim

This guide aims to support the facade and cladding industry in reducing the whole-life carbon emissions of their designs. To achieve this aim, this guide provides practitioners with the knowledge to quantify embodied carbon emissions of facade systems.

Whilst this document is focused on the *embodied* carbon of facades, it is important to understand that sustainable buildings must be designed with consideration for minimising whole-life carbon emissions.

A whole-life carbon approach requires designers to optimise the impact of their designs with consideration for both the embodied and operational carbon emissions over the life of the building to avoid the unintended consequences that may result from assessing each in isolation.

In writing this guide the authors have had to balance accuracy, consistency, flexibility and prescriptiveness to support the application of the methodology at different times during the design phase.

At the time of publication there remains many data gaps that limit the accuracy of the assessment of facade systems. In publication of this guide, it is intended to draw the focus of the industry to address these limitations. Where appropriate this guide presents default assumptions to address data gaps and in doing so provides a degree of consistency.

It is intended that this document will be updated over time to reflect the latest knowledge and experience in the field of whole life carbon assessment of facade and cladding systems.

1.2. Aligned documents

The methodology described herein provides a degree of consistency to support the comparison of embodied carbon assessments. The methodology follows the framework set out in BS EN 15978 (1) and is aligned with other industry documents.

In the UK the current framework for appraising the environmental impacts of the buildings is documented in BS EN 15978:2011 - *Sustainability of construction works — Assessment of environmental performance of buildings — Calculation method* (1). BS EN 15978 sets out the calculation method for the assessment of the environmental performance of a building. Designers should be aware that BS EN 15978 is currently under revision.

Construction industry bodies have developed supporting documents to guide the interpretation of the method in BS EN 15978 for specific industry disciplines:

- RICS Professional Statement (RICS PS): *Whole Life Carbon assessment for the built environment* (2017) (5);
- IStructE: *How to calculate embodied carbon 2nd Edition* (2022) (6);
- CIBSE TM65 *Embodied carbon in building services: A calculation methodology* (2021) (7).

The methods described in documents listed above are not specific to the facade engineering discipline. The purpose of this document is to address this gap by providing an aligned method to calculate the embodied carbon of facade and cladding systems.

This document aligns with the calculation method set out in BS EN 15978 providing specific guidance and interpretation for life cycle assessment (LCA) of facades and cladding systems. It is anticipated the results of assessments undertaken to this guide will feed into broader project-wide whole life carbon assessments. To this end, the guide provides a degree of consistency with other industry guidance as referenced in this document.

This document builds on the CWCT's portfolio of guidance documents related to sustainability. For background information to the topic of sustainability in facades and cladding, readers are referred to the CWCT's Sustainability Guide 01 *An Introduction to Sustainability in Facades* (8). Furthermore, for guidance on the common terms and phrases associated with the field of sustainability readers are referred to the CWCT's *Climate Jargon Buster* (9).

1.3. Scope of document

This methodology concerns the assessment of facade systems. The main body of this document focuses primarily on newly built facades, while further guidance on how to apply this methodology to existing facades will be included in future revisions of the document and supplementary guidance documents by the CWCT.

A facade is commonly referred to as an external wall or part of a building envelope. All components required to meet the functional, technical, and aesthetic performance of the facade must be considered. A facade may include curtain walling, masonry cavity walls, rainscreen cladding, composite panels, external rendering systems, precast concrete cladding, vertical and horizontal glazing systems, soffits, balustrades, canopies, balcony cladding, shading elements, steel framing systems (SFS) and other backing walls, as well as windows and doors, louvres, cappings and flashings. The complete assembly of the facade is to be considered in an LCA which includes an assembly of components comprised of the outer and/or infill cladding, associated support systems, finishes and accessories to form a complete facade system.

The primary structural frame, internal walls and partitions, sub-structure external walls, stairs and ramps, and roof systems (with the exception of glazed external roofing systems) are excluded from the scope of this document.

Within the RICS guidance (5), the facade is to be considered within the "Superstructure" building element group in whole life carbon assessments. More specifically, this includes the building elements 2.5 External Walls and 2.6 Windows and External Doors within this group as listed in Table 3 within the RICS guidance.

1.4. Life cycle stages overview

Life cycle stages provide a framework for the reporting of social, economic and environmental impacts of built assets as part of a Life Cycle Assessment (LCA). This framework is defined in BS EN 15643 (10) for building and civil engineering works. Further definition, specifically for the environmental assessment of buildings, is set out in BS EN 15978 (1).

The framework breaks down the life of a building into stages, and these stages into modules. These modules may be thought of as boxes, whereby the GHG emissions of a building or a facade system can be apportioned into the different boxes. In doing so this framework provides a degree of transparency and consistency to help understand when and where emissions occur.

The framework is illustrated in Figure 6 of BS EN 15978:2011 (1) and is reproduced in Figure 1 below. The same modular framework is presented in BS EN 15804:2012 (11) where it is used to structure the information reported in a construction product EPD.

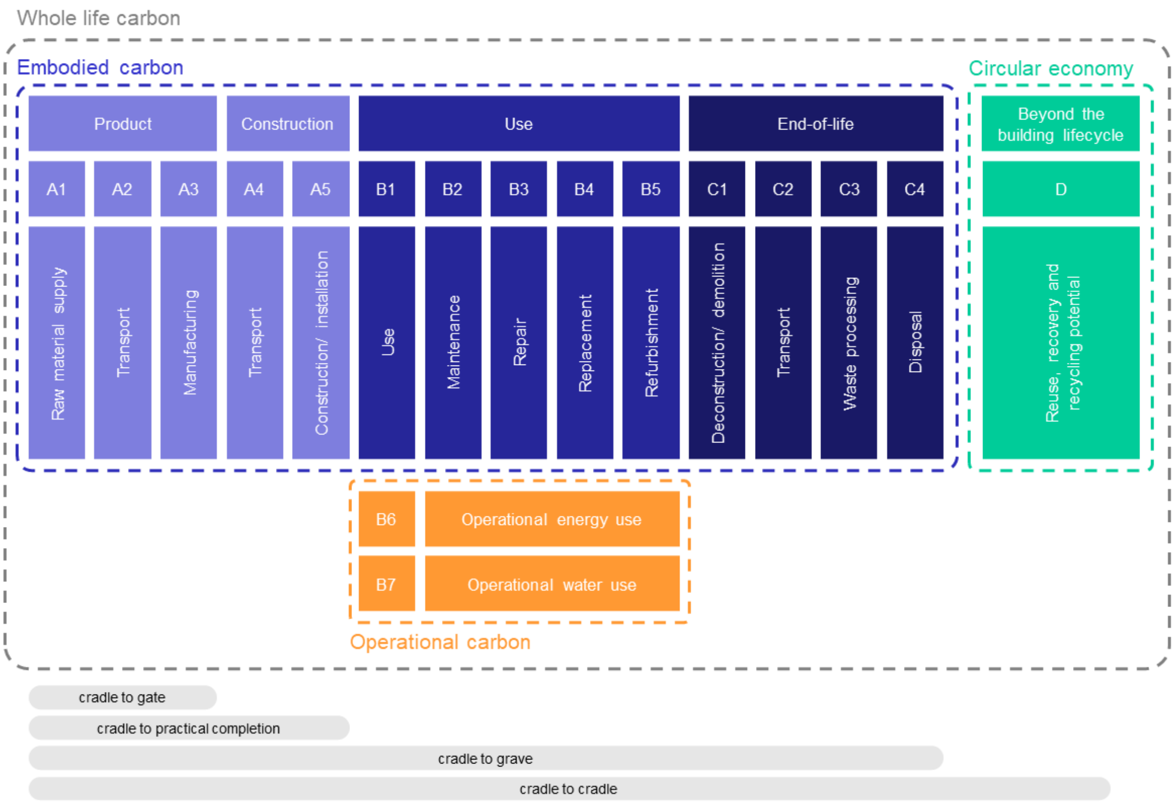


Figure 1 – Life cycle framework defined in BS EN 15978 (figure adapted from BS EN 15978)

The five life cycle stages are:

- **Product stage (includes modules A1 to A3).** This stage includes the emissions associated with the raw material extraction, processing, transportation to manufacturer and manufacturing (this includes facade mock-ups and spare materials or products (AKA "attic stock");
- **Construction process (includes modules A4 and A5).** This stage includes the emissions associated with the transportation to the building site and the installation into the building, including emission from on-site testing;
- **In use (includes modules B1 to B7).** This stage includes emissions associated with the use, maintenance, repair, replacement and refurbishment of the asset. Modules B1 to B5 consider the embodied carbon emissions within the use stage. Modules B6 and B7 consider the operational carbon emissions associated with the operational energy and water use of the asset being assessed;
- **End of life (includes modules C1 to C4).** This stage includes the emissions associated with the de-construction, transport away from site and end of life scenarios;
- **Benefits and loads beyond the system boundary (includes module D).** This stage exists outside the life cycle of the asset and considers the emissions and sequestration of carbon associated with recycling, recovery and reuse of materials.

For further information on the life cycle framework, modules and their boundaries readers should refer to the CWCT's *life cycle modules explained* guide (12).

1.5. Facade Form Factor and Facade Surface Area

The embodied carbon of a facade is typically calculated in units per square metre of facade surface area (FSA). In contrast, typical building carbon targets or assessments are reported in units per square metre of gross internal floor area (GIA). As a result, the ratio of a buildings' FSA to GIA, termed 'Facade Form Factor (FFF)', has a significant influence on the facades' contribution to the buildings' embodied carbon.

Recognising the significance of these parameters, this section provides further consistency to measuring a buildings' FSA and FFF.

1.5.1. Facade Surface Area (FSA)

The Facade Surface Area (FSA) refers to the surface area of the building envelope considered within the scope of the embodied carbon assessment. Note, this may/may not include horizontal surfaces of roofs, terraces and soffits.

When assessing the FSA, it is recommended to exclude all projections that occur outside of the thermal line (e.g. feature fins, external balconies and other attachments) from the assessment of the surface area.

In the absence of detailed information, a simplified FSA can be calculated by multiplying the perimeter of each floor with the respective floor-to-floor height. Where the embodied carbon assessment scope includes horizontal parts of the envelope (i.e. soffits) the surface area of these elements should be included.

1.5.2. Facade Form Factor (FFF)

The Facade Form Factor (FFF) is used to express the ratio of the Facade Surface Area (FSA) to the gross internal floor area (GIA).

$$\boldsymbol{FFF\ (m^2)} = \frac{\boldsymbol{FSA\ (m^2)}}{\boldsymbol{GIA\ (m^2)}} \qquad (1)$$

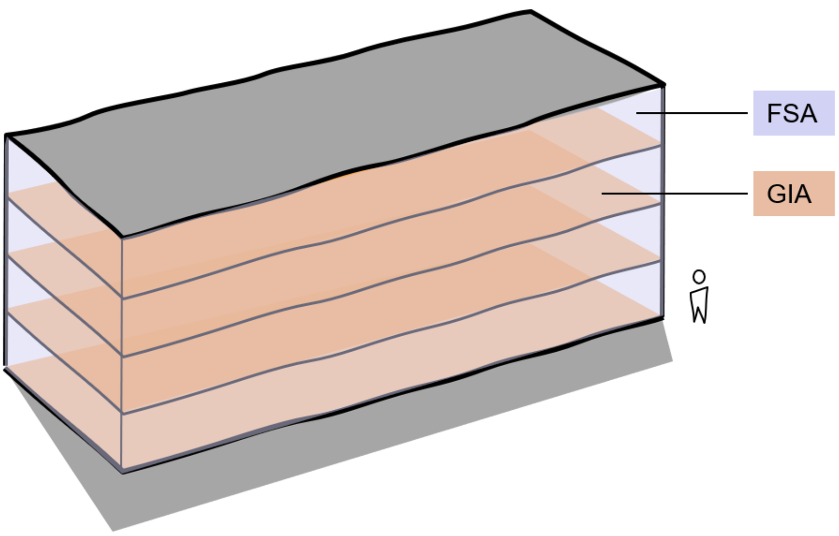


Figure 2 – Sketch of simplified building indicating 'FSA' and 'GIA'

Note: it is important to ensure that the GIA figure is constant and co-ordinated with stakeholders from other disciplines to maintain consistency.

The FFF is used for converting embodied carbon results between units per m^2 FSA and units per m^2 GIA. To calculate embodied carbon in units of 'kgCO_2e/m^2 GIA', simply multiply the embodied carbon in units 'kgCO_2e/m^2 FSA' by the FFF.

Designers should note it is important not to confuse the '*Facade Form Factor'* presented in this guide with other references to '*form factor'* typically used in evaluating heat loss from a building. The latter includes all external surfaces of the building, whereas the *'Facade Form Factor'* only includes those surfaces assessed as part of the embodied carbon scope.

At early stages designers should consider the influence of the buildings' FFF on the embodied carbon of the project. Figure 3 provides an indication of this influence. In exploring the influence of facade form factors, designers should consider:

- Optimising the shape and size of the floor plate;
- Review the floor-to-floor height.

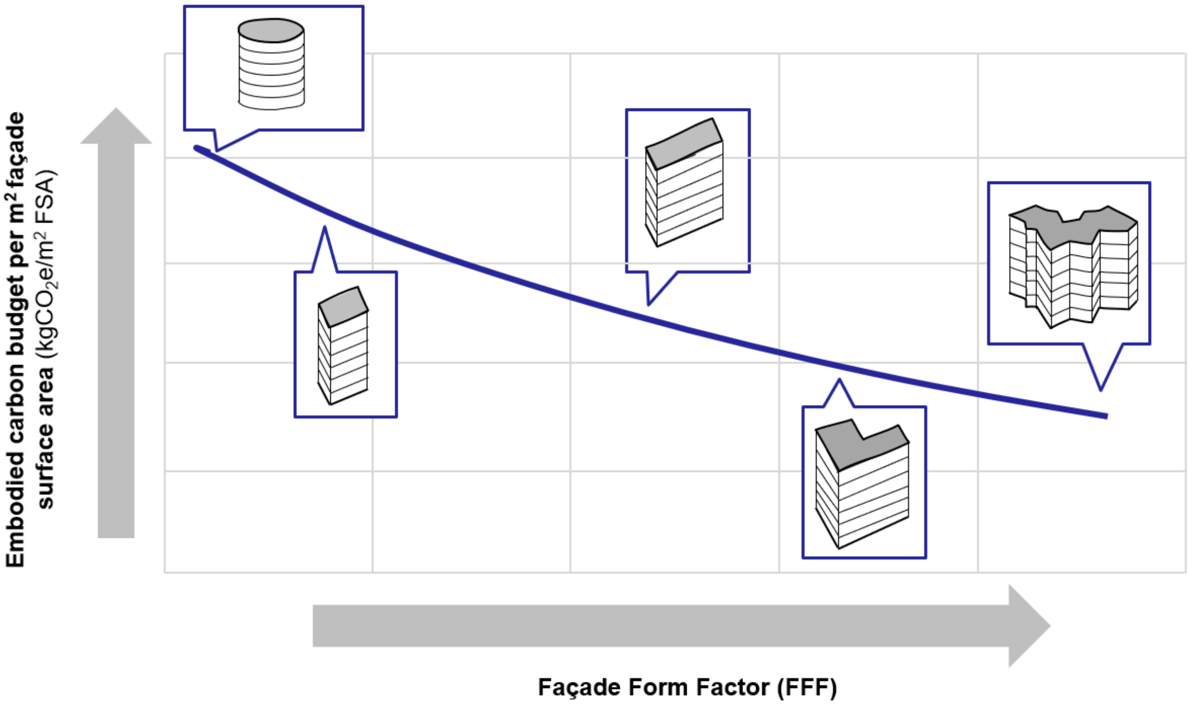


Figure 3 – The influence of Facade Form Factor on the embodied carbon budget per m² Facade area

1.6. Assessment approach

Facade embodied carbon should be assessed at all key project milestones to enable targeted carbon reductions. It is widely acknowledged that there exists greater design uncertainty at early stages. This uncertainty typically relates to the type, quantity and sourcing of materials and components within the design. Whilst this uncertainty that comes with early design stages can make undertaking assessments challenging, these early stages also provide the greatest opportunity to incorporate low-carbon design changes with minimal project impact.

The following approaches have been outlined to identify how embodied carbon can be assessed whilst addressing the lack of information at the time of the assessment regarding materials and component quantities.

An overview of the approaches is presented in Figure 4.

Refer to section 2.2.15 for detail on a carbon calculation scale-up factor that may be applied during different stages of an assessments to account for design and supply chain life cycle uncertainties. Designers should note this carbon calculation scale-up factor is separate and distinct to the material factor prescribed in the 'simplified' approach (section 1.6.2).

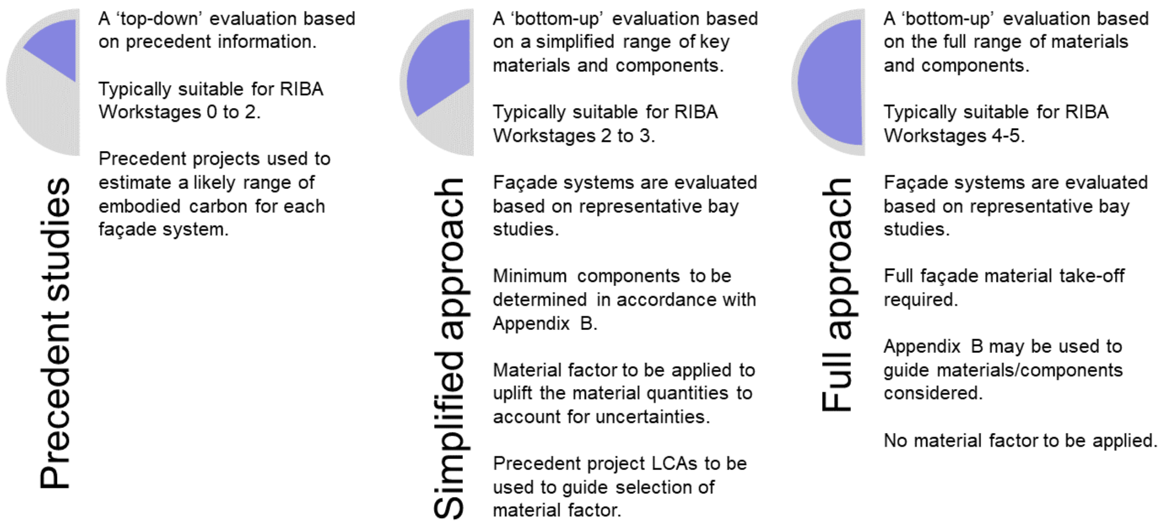


Figure 4 – Assessment approaches at different project stages

1.6.1. Precedent studies

At initial project design stages, where little is known about the facade systems other than potential typology, designers may estimate the embodied carbon based on a desk-study of relevant and representative LCAs from precedent projects. Where further refinement is required, precedent LCAs may be used to inform material quantities against which project-specific embodied carbon factors and assumptions may be made. Precedent studies may be used at early stages to define project-specific targets.

1.6.2. Simplified approach

As the project moves from concept to scheme through to detailed design, greater detail will be developed for each of the facade systems with plan, elevation, section and typical details developed as part of key milestone deliverables.

At scheme design stage for each main facade type, a bay study should be conducted to determine the volume of materials in a given facade surface area. A bay study is a typical facade elevation normally bounded by both the horizontal and vertical grid system. These typical framing bays should be representative of the facade system and the results of which can be scaled-up to approximate the total contribution of the facade system to the carbon footprint of the whole building.

Architectural elevations should be used to determine the Facade Surface Area (FSA) of the whole building for each facade system (refer to section 1.5). Refer to Section 2.3 for guidance on how to calculate the carbon footprint associated with all life cycle stages which can still be used in conjunction with the simplified approach.

As a minimum, quantities highlighted in Appendix B for each facade type should be calculated for each facade type using the simplified approach.

The facade contractor is responsible for providing the full facade design for construction with detailed build-ups. However, until a facade contractor has been appointed, the full detailed build-up for each facade is often unknown. This can lead to a significant under/over-estimation in facade carbon counting with secondary elements often unaccounted for or over estimated.

Designers are recommended to apply a material factor to the material quantities, Q_i, when undertaking a simplified approach. The simplified approach refers to assessments which do not account for all the components in a given facade system highlighted in Appendix B. The material factor should aim to account for the uncertainties associated with the assessed materials as well as providing a provision for unassessed materials and components.

A default material factor has not been presented in this guidance due to the variability in included elements that can be quantified at this stage. A material factor may be determined by using the breakdown of material elements from the precedent studies outlined in 1.6.2. These breakdowns will enable an approximate order of magnitude to be developed for missing elements. The simplified approach is to be used only prior to facade contractor appointment.

As part of the simplified approach a carbon calculation scale-up factor is recommended to be applied in accordance with section 2.2.15 in addition to the material factor.

1.6.3. Full approach

A full approach includes identifying and accounting for all the components of a given facade system(s) under assessment. Designers may find the information presented in Appendix B a useful checklist for the scope of components to be considered, noting the information is not exhaustive.

1.7. Off-site emissions

The supply chain of facade systems can be large and complex with multiple organisations responsible for different stages. The fabrication of components used within facade systems can go through multiple rounds of processing. The assembly of all facade systems will occur both on-site and off-site to a varying degree.

In principle, the emissions associated with the off-site fabrication of a component should be accounted for within the EPD of the component in question. In practice, the uptake and publication of EPDs in the industry is ongoing and currently designers may find limited data available for a particular product. For example, a designer may only find an EPD for sheet metal rather than a cut and formed metal rainscreen panel. The EPD for the sheet metal will not include the emissions associated with the additional transportation, fabrication and wastage that is required to form the panel.

It is recognised that data gaps, like the example described above, are likely to lead to underestimation of facades' embodied carbon.

To address these data gaps, this methodology provides a number of parameters for use. These parameters are not intended to replace carbon factors from EPDs and are intended to be used in addition to supplement for data gaps. These parameters are provided in section 2.2.2:

$\boldsymbol{ECF_{A2,F}}$	Transportation to off-site factory
$\boldsymbol{ECF_{A3,FAB,i}}$	Off-site fabrication emissions
$\boldsymbol{ECF_{A3,ASS}}$	Off-site assembly emissions
$\boldsymbol{ECF_{A3,W}}$	Off-site wastage rates

A definition of "fabrication", "assembly" and "installation" is provided in the Terminology section at the start of this document.

It should be noted that the application of these coefficients is at the discretion of the designer and should be based on a careful review of the scope of emissions within the referenced carbon factors used in the assessment.

The following cases provide some indicative examples to guide designers in understanding when the application of the above coefficients is appropriate.

- An assessment is being undertaken on a unitised curtain walling system at an early design stage. The carbon factors for the facade components (i.e. IGU, extruded aluminum profiles etc.) have been taken from separate EPDs for each product. In this instance the emissions associated with the transportation to a factory, off-site assembly of the components into a unitised panel, and associated wastage are not captured within the scope of the EPDs referenced and therefore parameters $ECF_{A2,F}$, $ECF_{A3,ASS}$ and $ECF_{A3,W}$ are applied.
- The same unitised curtain walling is being re-assessed later in the design. At this time an EPD for the unitised curtain walling product is available. This EPD includes off-site assembly emissions and associated wastage. In this instance none of the parameters are applied.
- An assessment of a site-assembled metal rainscreen facade is being undertaken. Due to data limitations, an EPD for sheet metal is being used as the referenced carbon factor for the rainscreen panels. As a result, emissions associated with transportation to a factory, cutting, forming and associated off-site wastage of the panels are not included. In this instance parameters $ECF_{A2,F}$, $ECF_{A3,FAB}$ and $ECF_{A3,W}$ are applied.
- The same rainscreen panels are instead being used as part of unitised curtain walling. In this instance the emissions associated with the off-site assembly of the curtain walling panels are accounted for by application of parameter $ECF_{A3,ASS}$.
- An embodied carbon assessment is being undertaken on a stick curtain walling system. The carbon factors for the facade components (IGU, aluminum profiles etc.) has been taken from separate EPDs for each product. In this instance the EPDs used cover the full scope of off-site assembly and hence the off-site assembly coefficients should not be applied. If however, the EPD for the aluminium extrusion does not account for the wastage generated by cutting down to size, $ECF_{A3,W}$ should be applied.

Designers should take care to ensure that all relevant factory-assembled emissions are reported within the EPD and are encouraged to seek clarity from the EPD's supplier where uncertain.

2. Calculation

The process for calculating embodied carbon for facades is summarised in Figure 5. Each step within this overall process is described with more detailed guidance in the referenced sections within this document.

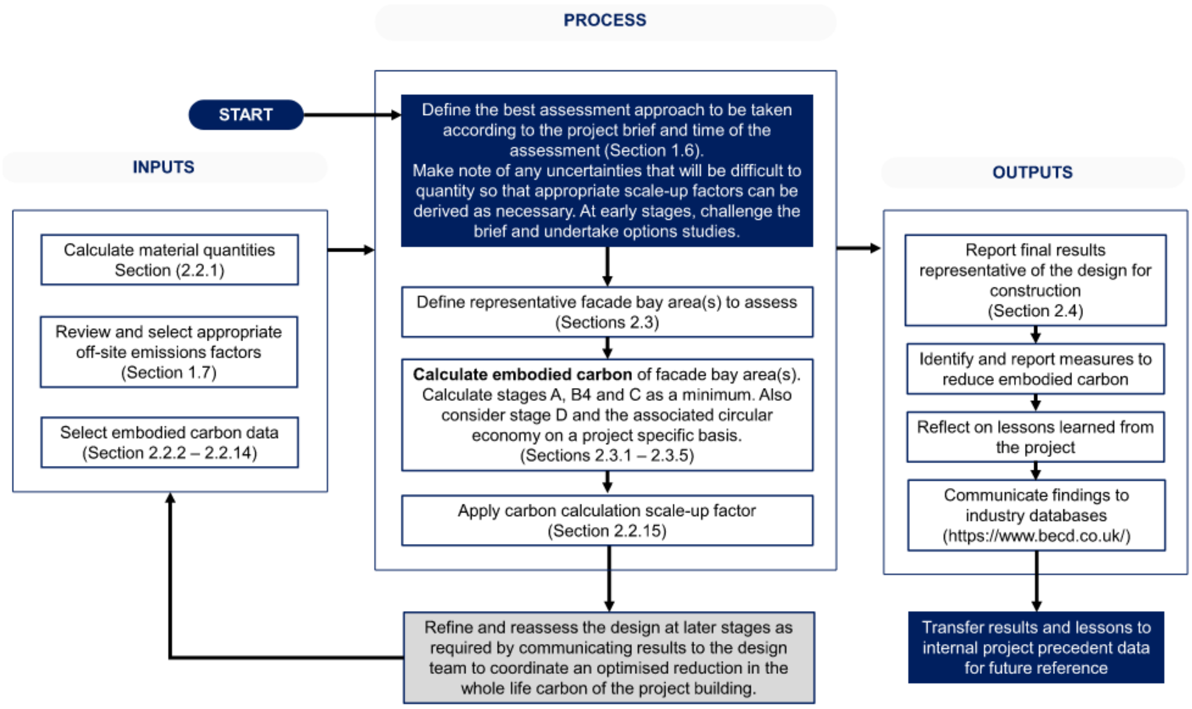


Figure 5 – Calculating facade embodied carbon process overview (adapted from The IStructE (6))

The following sections provide guidance on the calculation of embodied carbon, including inputs, process, and outputs needed for an assessment.

2.1. Scope of calculation

2.1.1. Life cycle modules

As a principle, **Designers/Assessors must consider as many life cycle modules as possible** within the assessment.

The assessment must include the following minimum life cycle modules:

- Product stage [A1 – A3];
- Construction process stage [A4 – A5];
- Replacement stage [B4];
- End of life [C1 – C4].

Designers may be required to expand the minimum scope of calculation where coordination with other standards and guides is required.

Further advice on the consideration of Modules B1 – B3 and B5 is provided in section 2.2.5. and the CWCT's *Life cycle modules explained* (12).

The scope of this guidance is limited to embodied carbon and therefore does not include operational carbon modules B6 and B7. At the time of writing, it is anticipated further guidance will support Designers in the consideration of facades impact on the operational carbon of the asset.

2.1.2. Components

A facade system may be considered as an assembly of materials and components. Various types of facade system exist, each includes different materials and components important to the make-up and performance of the system. This can include the cladding panel and glazing unit, as well as other associated components integral to the performance of the system such as thermal insulation, firestopping and cavity barriers, brackets, and membranes.

The impact of an individual component on the total embodied carbon of a facade system is primarily a function of its mass and embodied carbon factor. Consequently, caution must be taken when determining the minimum facade components to include in an LCA to ensure small or lightweight components are included where required to avoid underestimation of a facade system's environmental impact.

BS EN 15978 section 9.4.3, and BS EN 15804 section 6.3.6 (11) provide the following criteria for including/excluding of inputs and outputs which has been interpreted here for relevance to facades:

All components in a facade system must be considered if they meet the following criteria:

- The facade component is greater than 1% of the total facade system mass; and
- The sum of neglected components is not greater than 5% of the total facade system carbon equivalent or mass.

The criteria provided above should be used to guide the selection of components considered. Furthermore, designers should take care to ensure that components with a high carbon intensity, albeit low mass, are included where the inclusion significantly impacts the results of the assessment.

It is recognised that limitations in the availability of data exists. At times designers will be required to make assumptions regarding the material mass and embodied carbon factor, particularly at early design stages. To this end, **any assumptions made should be based on reasoned judgement in combination with plausible considerations based on current practice. Such assumptions must be reported in a calculation.**

The reasonableness of such assumptions will vary on the project stage at the time of the assessment. The level of detail and data available to quantify each facade component will increase throughout the design development.

Appendix B includes embodied carbon calculation component checklists for different facade typologies. It is important to note that the checklists are not intended to be exhaustive and instead provide a prompt to encourage a detailed appraisal of all the components. Project-specific factors must be considered which may require additional components for the facade system to be included in calculations.

2.2. Inputs

A summary of the inputs required to calculate embodied carbon is presented in Table 1.

Life cycle modules	Input required	Section reference
All	Material or component quantities	Section 2.2.1
A1 – A3	Product (A1 – A3) embodied carbon factors	Section 2.2.2
A2	Transport distance and mode of transport to off-site factory [1]	Section 2.2.2
A3	Off-site fabrication emissions[1]	Section 2.2.2
A3	Off-site assembly emissions[1]	Section 2.2.2
A3	Off-site wastage rates[1]	Section 2.2.2
A4	Transport distance and mode of transport from factory to site	Section 2.2.3
A5	Site wastage rates[2][	Section 2.2.4
A5	Site activities emissions	Section 2.2.4
B1	Use	Section 2.2.5
B2	Glazing cleaning emissions	Section 2.2.6
B3	Repairs	Section 2.2.7
B4	Reference study period	Section 2.2.8
B4	Component lifespan	Section 2.2.8
B5	Refurbishments	Section 2.2.9
C1	Demolition and deconstruction emissions	Section 2.2.10
C2	Transport distance and mode of transport	Section 2.2.11
C3/C4	End-of-life scenarios	Section 2.2.12 and 2.2.13
D	Reuse, recovery, and recycling potential	Section 2.2.14
A – C	Carbon calculation scale up factor	Section 2.2.15
A – C	Carbon sequestration in timber	Appendix D

Note:
[1] These coefficients are not intended to replace carbon factors from EPDs and are intended to be used in addition to compensate for the data gaps identified in section 1.7.
[2] As noted in section 2.2.4 Site wastage emissions, site wastage emissions may be taken as zero for off-site assembled Facade systems.
[3] Where references are provided for inputs described in each section, the most current version of each reference should be used at the time of applying this guide.

Table 1 – Summary of required inputs

2.2.1. Material and component quantities

The quantity (kg) of materials and components, denoted as $\boldsymbol{Q_i}$ herein, may be evaluated by a range of methods. The most suitable method will depend on the information, level of detail and tools available at the stage of design, and could include:

- Project drawings;
- BIM models;
- Previous project experience;
- A Quantity Surveyor's cost plan;
- Bill of Quantities.

Do not let the uncertainty of material quantities prevent an assessment being undertaken. The level of uncertainty in the material quantities will reduce during the project design. This supports the need to repeat calculations at key project stages.

Note, section 1.6.2 introduces a material factor on the material quantities where the simplified approach is being used.

The emissions associated with the wastage of materials and components during off-site and on-site activities is accounted for in sections 2.2.2 Module A3: Off-site wastage emissions and 2.2.4 Site wastage emissions respectively.

2.2.2. Inputs for modules A1-A3: product

The embodied carbon associated with a given component is simply a product of the material quantity and relevant embodied carbon factor.

$$\boldsymbol{EC_{A13,i}} = \boldsymbol{Q_i} \times \boldsymbol{ECF_{A13,i}} \tag{2}$$

Where:

$\boldsymbol{Q_i}$	= quantity of *i*th material (kg)
$\boldsymbol{ECF_{A13,i}}$	= module A1 – A3 embodied carbon factor for *i*th material ($kgCO_2e/kg$)

Note, the term ‘ith’ is used as a generic reference to identify the instance of any single component or material within a list of components from 0 to n. (i.e. 1st component, 2nd component, 3rd component, … ith component, … nth component).

A1-A3 Embodied Carbon Factor (ECF)

Embodied Carbon Factor (ECF) is the term used to refer to the Global Warming Potential (GWP) of a given quantity of a given material or component. An ECF is measured in units of $kgCO_2e$ per unit quantity (i.e. kg or m^2) of material or component.

The A1 – A3 Embodied Carbon Factors (ECF_{A13}) includes the carbon emissions associated with:

- Raw material extraction and supply (A1);
- Transport to manufacturing plant (A2);
- Manufacturing and fabrication (including packaging, and temporary materials) (A3);
- Waste or losses associated with the manufacture and transportation.

The $\boldsymbol{ECF_{A13}}$ associated with a given material or component will depend on the material specification and the location where the product/material is to be manufactured.

Select a carbon factor that *best represents* the understanding of the source and specification of the material at the time of the calculation. In the early project stages this may require making key assumptions regarding the material. These assumptions must be reported within the assessment.

Refer to Appendix C for guidance on how to select carbon emission factors specific to glazing build-ups in the absence of project specific data at the time of the assessment. Refer to Appendix D for guidance on how to consider sequestration and biogenic carbon. It is anticipated that additional guidance specific to selecting embodied carbon emission factors for other facade products will be provided in the future.

This methodology does not currently provide guidance on the emissions associated with packaging and protection materials beyond those present within the assumed carbon factor data.

It is important for designers to ensure that both material quantity (Q_i) and embodied carbon factor

($ECF_{A13,i}$) are reported in compatible units (e.g. **kg** and $kgCO_2e$/**kg** or; **m²** and $kgCO_2e$/**m²**). Where this is not the case, designers will need to convert the material quantity into compatible units.

There are multiple sources of ECFs available to a designer. This can be identified predominantly under the following categories:

- Environmental Product Declaration (EPDs);
- Open-source databases.

Environmental Product Declaration (EPDs):

When considering EPDs for carbon factor data, designers should take care to ensure the EPD is representative of the product in question and the level of detail known at the time of the assessment. Designers should refer to CWCT guide 'How to read an EPD' (13) for further guidance in interpreting EPDs and other data sources. **Be sure to always ask the supplier for the EPDs of their products to help create a demand for reporting EPDs in the industry.**

The scope of the Life Cycle Assessment (LCA) reported within the EPD will be based on either a functional and or declared unit. These units provide a reference by which the LCA can be assessed. A functional unit is used when one or more measurable functional performance values can be defined for the product. A declared unit is used when the function of the product is unknown or the LCA does not consider all life cycle modules. Examples of a declared unit include length (1m), area ($1m^2$) or mass (1kg).

Designers should be aware that multiple types of EPDs exist:

- Product-specific EPDs cover a single specific product from a single manufacturer from a single specific manufacturer. Note the results presented could be an average from multiple factories owned by the single manufacturer;
- Manufacturer-specific (AKA group) EPDs cover multiple similar products from a single manufacturer;
- Industry-wide (AKA average or collective) EPDs cover a broad product type (e.g. MDF or cement) and are developed by an industry association. These EPDs declare the average product of multiple companies in a clearly defined sector or geography.

EPDs are available either directly from the manufacturer or often via online repositories. The IStructE guide '*How to calculate embodied carbon'* (6) section 2.2.2 (Module A2: transport to factory emissions) presents several links to online EPD repositories designers may use.

Open-source databases:

Open-source databases provide an alternative source for carbon factors. When using data from an open-source database, designer should consider that:

- Databases tend to be based on a specific geographic region;
- The carbon factor data presented is likely to be an average figure of multiple EPDs;
- Some databases are limited to providing carbon factors for only modules A1 – A3.

The IStructE guide '*How to calculate embodied carbon'* Appendix A (6) presents several links to databases designers may use. A selection of these databases, common to the European market, are presented in Table 2.

Region	Database	Notes	Link
UK	ICE database	Wide ranging material database covering Modules A1–A3	https://carbon.tips/ice3
UK	BRE Verified BS EN 15804 EPD	EPDs for specific products, with a range of modules	https://carbon.tips/breEPD
UK	BRE IMPACT	350 BS EN 15804-compliant datasets modelled in SimaPro	https://carbon.tips/umx
Europe	European Aluminium EPD Programme	EPDs for specific aluminium products, with a range of modules	https://carbon.tips/lca8
Switzerland	Ecoinvent	Database with data covering range of sectors including construction	https://carbon.tips/lca23

Table 2 – European open-source databases

When interpreting ECF data, designers should note:

- Take care not to confuse units ‘$kgCO_2$’ and ‘$kgCO_2e$’. The former refers to emission of carbon dioxide only, the latter considers all greenhouse gases;
- Designers should note that the ECF is typically reported in scientific notation. (e.g., 5.99E-01 = 0.599).

Module A2: transport to factory emissions

This section provides guidance on the application of additional emissions associated within the transportation of materials or components to an off-site factory for further processing. For guidance on when the application of the parameter presented is appropriate ($ECF_{A2,F}$), refer to section 1.7.

$$ECF_{A2,F,i} = \sum_{mode} \left[TD_{mode} \times \frac{TEF_{mode}}{1000} \right] \quad (3)$$

Where:

$ECF_{A2,F,i}$ = transportation to factory, embodied carbon factor for i^{th} component ($kgCO_2e/kg$)

TD_{mode} = transport distance for each transport mode (km)

TEF_{mode} = transport emission factor for each transport mode ($gCO_2e/km.kg$)

1000 = conversion from grammes to kilogrammes

True transportation embodied carbon factors for each material will not be known until the project is completed and the transportation modes and distances have been recorded.

Where transport distances and modes are unknown at the time of assessment, it should be assumed that materials and components are sourced from within the country of manufacture (i.e. “Nationally” in accordance with Table 4 in section 2.2.3 by road via an average laden HGV (=0.10614 $gCO_2e/kg.km$ in 2022).

In later-stage assessments, where supply chains have become more certain, designers should alternatively evaluate specific transportation distances and emissions factors.

Module A3: Off-site fabrication emissions

This section provides guidance on the application of additional emissions associated with the operational energy demand of the factory fabrication process. This includes the emissions associated with the operation, lighting, space heating and cooling of the factory environment and equipment.

Designers should ensure these emissions are not already accounted for within the assumed EPD data to avoid double-counting emissions. For guidance on when the application of the parameter presented ($\boldsymbol{ECF_{A3,FAB,i}}$) is appropriate, refer to section 1.7.

In early-stage assessments the approach shown in equation (4) and the default figure in equation (5) and Table 3 may be used to evaluate these emissions. Note, guidance on the fabrication and assembly of glazing units is provided separately in Appendix C.

$$\boldsymbol{ECF_{A3,FAB,i} = FEI_i \times GCF} \tag{4}$$

Where:

$\boldsymbol{ECF_{A3,FAB,i}}$ = off-site fabrication emissions factor for the i[th] component ($kgCO_2e/kg$)

$\boldsymbol{FEI_i}$ = factory energy intensity (kWh/kg of i[th] component)

$\boldsymbol{GCF}$ = grid carbon factor ($kgCO_2e/kWh$)

Equation (5) provides a default factory energy intensity (FEI). Designers are advised that the default figure presented is based an appraisal of only one data point from a sheet metalwork fabricator based in the UK. Designers are encouraged to speak directly with fabricators to evaluate project-specific factors as the design develops and supply chains become confirmed.

$$\boldsymbol{FEI_i = 4\ kWh/kg} \tag{5}$$

Designers should take care to distinguish between the FEI_i parameter applied above and FEI parameter applied in section 2.2.2 Module A3: Off-site assembly emissions.

The FEI_i parameter is applied at the component-level (i.e. accountable to a specific component(s) within a facade system). To support this the factory energy intensity provided in equation (5) is normalised by a unit mass of the component (kg).

On the other hand, the FEI parameter (section 2.2.2 Module A3: Off-site assembly emissions) is applied at the system-level (i.e. accountable to a facade system generally rather than a specific component). To support this the factory energy intensity provided in equation (7) is normalised by the square meter facade surface area.

Table 3 presents a selection of example electricity grid factors that designers may assume. Designers may use data from other sources and are encouraged to use factors that are current and specific to location geography taking consideration for electricity generation, transmission and distribution, and well-to-tank emissions.

Location	Grid Carbon Factor, GCF
UK	0.26 $kgCO_2e/kWh$[2][4]
Europe	0.30 $kgCO_2e/kWh$[1][3]
US	0.45 $kgCO_2e/kWh$[1][2]
Australia	0.88 $kgCO_2e/kWh$[1][2]
Asia	0.59 $kgCO_2e/kWh$[1][3]
Middle East	0.55 $kgCO_2e/kWh$[1][3]

Note:
[1] Data from *Carbon Footprint* 2020 (14).
[2] Includes both 'general' and 'T&D' (transmission and distribution emissions).
[3] Based on an average of the countries available
[4] Data from BEIS greenhouse gas reporting factors 2022 (15) includes emissions from generation, transmission and distribution (T&D) and well-to-tank (WTT) emissions for both generation and distribution.

Table 3 – Example electricity grid factor

The use of grid carbon factors, as presented above, implicitly assumes that factory emissions are a result of solely electricity use. In practice it is likely that factory emissions result from a range of fuel sources. This simplified assumption proposed above is suitable for early-stage assessments but should be reviewed in later stages as the supply chain becomes confirmed.

In later-stage assessments, where supply chains have been confirmed, designers should work with the supply chain to evaluate factory-specific values of Factory Energy Intensity (FEI), making use of relevant geographic Grid Carbon Factors (GCF) for all fuel sources.

- When evaluating the FEI of a factory, the following energy consumption should be included and evaluated over a representative 12-month period:
  Factory equipment operational energy use;
- Factory space heating and cooling energy use;
- Factory lighting energy use;
- Any other energy consumption required to directly run the factory.

Notably, the energy use associated with the power, heating and cooling requirements of supporting administrative and/or office facilities should *not* be included. These emissions are outside the Product Stage system boundaries presented in BS EN 15804 (11).

In evaluating the FEI, designers will also be required to estimate the total quantity of component (kg) or facade system (m^2) produced in the same 12-month period.

Where renewable energy is generated at the factory, the resulting reduction to emissions may be quantified by adjusting either the FEI or GCF. Where this is done, the assessment report should make clear how this has been adjusted.

Module A3: Off-site assembly emissions

This section provides guidance on the application of additional emissions associated with the operational energy demand of the factory assembly process. This includes the emissions associated with the operation, lighting, space heating and cooling of the factory environment and equipment. Designers should ensure these emissions are not already accounted for within the assumed EPD data to avoid inaccurately estimating emissions. For guidance on when the application of the parameter presented ($\boldsymbol{ECF_{A3,ASS}}$) is appropriate, refer to section 1.7.

In early-stage assessments the approach shown in equation (6) and the default figure in equation (7) and Table 3. may be used to evaluate these emissions. Note, guidance on the fabrication and assembly of glazing units is provided separately in Appendix C.

$$\boldsymbol{ECF_{A3,ASS} = FEI \times GCF} \tag{6}$$

Where:

$\boldsymbol{ECF_{A3,ASS}}$	= factory assembly emissions ($kgCO_2e/m^2$ FSA)
$\boldsymbol{FEI}$	= factory energy intensity (kWh/m^2 of facade surface area (FSA))
$\boldsymbol{GCF}$	= grid carbon factor ($kgCO_2e/kWh$)

Equation (7) provides a default factory energy intensity (FEI). Designers are advised that the default figure presented is based on appraisal of four data points from predominately unitised curtain walling assembly facilities in the UK and Europe. Whilst a default is provided, designers should note the datapoints indicated that the FEI may vary significantly and hence designers are encouraged to evaluate project-specific figures as the supply chain becomes confirmed.

$$\boldsymbol{FEI = 30\ kWh/m^2\ FSA} \tag{7}$$

Table 3. presents a selection of example electricity grid factors that designers may assume. Designers may use data from other sources and are encouraged to use factors that are current and

specific to location geography taking consideration for electricity generation, transmission and distribution, and well-to-tank emissions.

For background and guidance on how to evaluate project specific GCFs refer to the information presented in section 2.2.2 (Module A3: Off-site fabrication emissions).

Module A3: Off-site wastage emissions

This section provides guidance on accounting for the wastage of material during off-site factory assembly. For guidance on when the application of the parameter presented ($\boldsymbol{ECF_{A3,w}}$) is appropriate, refer to section 1.7.

> In this context "waste" refers to the materials and components consumed within the off-site fabrication or assembly which do not ultimately form part of the installed facade system. This includes material and components lost due to damage or off-cuts during the off-site processing. Notably, this definition does not include packaging materials, which should be accounted for within the carbon factor of materials and components assumed.
>
> Designer should take care to ensure these emissions are not double-counting with the scope of emissions assumed within the carbon factor for the materials and components.

The emissions associated with the wastage of material off site during off-site fabrication and assembly are accounted for within life cycle module A3. These emissions are accounted for through the provision of embodied carbon factor, $ECF_{A3w,i}$. This factor accounts for the emissions associated with the manufacture (A1-A3), transportation to waste processing (C2) and end-of-life (C3/C4) of wasted components. Note the transportation to site (A4) and deconstruction emissions (C1) associated with factory waste can be assumed to be zero as the wasted components are not being transported or installed on site.

$$\boldsymbol{ECF_{A3w,i} = WF_i \times (ECF_{A13,i} + ECF_{A2F,i} + ECF_{C2,i} + ECF_{C34,i})} \quad (8)$$

Where:

$\boldsymbol{ECF_{A3w,i}}$	= construction waste embodied carbon factor for i^{th} material ($kgCO_2e/kg$)
$\boldsymbol{WF_i}$	= waste factor for i^{th} material given by equation (9)
$\boldsymbol{ECF_{A13,i}}$	= module A1 – A3 embodied carbon factor for i^{th} material ($kgCO_2e/kg$)
$\boldsymbol{ECF_{A2F,i}}$	= transportation to factory, embodied carbon factor for i^{th} material ($kgCO_2e/kg$)
$\boldsymbol{ECF_{C2,i}}$	= transportation to waste processing, embodied carbon factor for i^{th} material ($kgCO_2e/kg$)
$\boldsymbol{ECF_{C34,i}}$	= waste processing and disposal emissions ($kgCO_2e/kg$)

$ECF_{A3w,i}$ embodied carbon factor includes carbon sequestration for any timber products wasted during construction, as module A3 also accounts for the end of life of timber products wasted in $ECF_{C34,i}$. As explained in Appendix D, sequestration should be included where end of life emissions are accounted for.

$$\boldsymbol{WF_i = \frac{WR_i}{1 - WR_i}} \quad (9)$$

Where:

$\boldsymbol{WR_i}$	= waste rate (proportion of the total quantity of the i^{th} material brought to the factory that ends up as waste).

At early design stages, where the supply chain is not confirmed, the waste rate may be taken from similar product EPDs or as follows:

- Components requiring cutting to size in the factory*: $WR_i = 15\%$
- Components not requiring cutting to size in the factory: $WR_i = 3\%$

*This waste rate should not be limited to only those facades assembled off-site. Many components of predominately site-assembled facade systems (e.g. stick curtain walling and rainscreen systems) will require components to be cut to size in the factory (i.e. aluminium extrusions and folded metal panels).

The default waste rates presented are intended to be broadly indicative and provide consistency to the assessments until a more detailed analysis of waste rates can be undertaken. Designers should note that the assumed waste rates are likely to not be appropriate for the following materials and components:

- Glass / IGUs (refer to Appendix C);
- Natural stone panels;
- Bricks and blocks.

For these products designers should consult with suppliers to identify an appropriate waste rate.

At later design stages, waste rates may be taken from product-specific EPDs. Alternatively, where a supplier is seeking to establish a waste rate, this may be evaluated from the difference between the quantity of component included within the designed facade and the quantity of component brought into the factory.

2.2.3. Inputs for module A4: transport to site

Module A4 includes the carbon emissions associated with the transport of products from the factory gate to the construction site. These emissions are a function of the transportation distance and carbon-intensity of the transport mode, see equation (10). The emissions must account for all transportation between the manufacturing plant and the site, including all interim stops.

$$\boldsymbol{ECF_{A4,i}} = \sum_{mode} \left[\boldsymbol{TD_{mode}} \times \frac{\boldsymbol{TEF_{mode}}}{\mathbf{1000}} \right] \qquad (10)$$

Where:

$\boldsymbol{ECF_{A4,i}}$	= transportation to site, module A4 embodied carbon factor for i^{th} material ($kgCO_2e/kg$)
$\boldsymbol{TD_{mode}}$	= transport distance for given mode of transport (km)
$\boldsymbol{TEF_{mode}}$	= transport emissions factor for given mode of transport ($gCO_2e/km.kg$)
1000	= conversion from grammes to kilogrammes

This includes the emissions associated with the delivery of facade systems or their components to the construction site, and the transportation of construction equipment to and from the site. Note, data to quantify emissions associated with transportation of construction equipment is currently limited and not included within the approach described herein.

True transportation embodied carbon factors for each material will not be known until the project is completed and the material transportation modes and distances have been recorded. In the absence of precise information, the information that follows can be used to estimate $ECF_{A4,i}$.

The transport distance should be calculated based on the distance between the manufacturing location and the project site which is subject to the anticipated supply chain route of each item. When specific information is unavailable, default values may be used in accordance with Table 4 based on assumptions of country of sourcing. These assumptions must be updated to include project-specific information as and when available.

The Transport Emissions Factors (TEF) can be obtained from the '*Greenhouse gas reporting: conversion factors'* document published annually by the Department for Business, Energy & Industrial Strategy (BEIS) (15). TEFs for the appropriate year should be used in the calculation. The dataset gives TEFs based on type of vehicle, percentage of load and the transport distance. The appropriate type of vehicle and amount of load should be estimated based on the product or system mass to pick the most representative TEF.

Designers should be aware that TEFs may vary according to the country where the project is located, or where the product is sourced from or transported through. If reliable sources of TEFs are available for the specific region in such cases, those values may be used in calculation.

The size of the vehicle, the size of one load, and the number of trips required must be worked out based on the volume, mass and nature of the products transported. The material or system mass is quantified as an input for modules A1-A3 (refer to 2.2.2) and must account for any material losses during transport.

Where the specific mode of transport is unknown at the time of assessment, designers should assume:

- **Road transport of *facade components*** based on an average laden diesel HGV (=0.10614 $gCO_2e/kg.km$ in 2022)
- **Road transport of *facade systems*** based on an 50% laden diesel HGV (=0.12145 $gCO_2e/kg.km$ in 2022)
- **Sea transport** based on an average container ship (=0.01614 $gCO_2e/kg.km$ in 2022)

The units have been changed to suit metric units. When sourcing data directly from the '*Greenhouse gas reporting: conversion factors'* document, designers must take care to appropriately convert the units in line with the formula and available data.

Note: The defaults above differentiate the road transportation of facade systems and facade components, based on the assumption that greater packing efficiencies can be achieved with the latter. Where detailed data is available of packing efficiencies these should be used.

A4 emissions should therefore be calculated on a project-specific basis, even though some product EPDs provide data for A4. Where EPD data is used for these modules, the carbon values should be adjusted accordingly to fit the project-specific scenarios.

Procurement scenario	Distance by road (km)	Distance by sea (km)
Locally manufactured	50	-
Nationally manufactured	300	-
Manufactured in Europe	1,500	-
Globally manufactured	200	10,000
Note: The above distances are applicable to projects located in the UK and include a generic allowance for interim storage depots before reaching the construction site. These should be adjusted accordingly based on project location if in a different country.		

Table 4 – Default transport scenarios for the UK (Source: RICS guidance (5))

The transport of people and commuting of employees is currently excluded from the calculations as the emissions associated with these activities are not attributed to the project but rather to the individual employees or the companies they work for.

2.2.4. Inputs for module A5: construction / installation

Site wastage emissions

In this context "waste" refers to the materials and components consumed within the on-site installation which do not ultimately form part of the installed facade system, this includes material and components lost due to damage or off-cuts. Designers should take care to ensure these emissions are not double-counting with the scope of emissions assumed within the carbon factor for the materials and components.

This methodology does not currently provide guidance on the emissions associated packaging, protection materials or temporary works beyond those present within the referenced carbon factor data.

The emissions associated with the wastage of material on site during construction are accounted for within life cycle module A5 through the provision of embodied carbon factor, $\boldsymbol{ECF_{A5w,i}}$. This factor accounts for the emissions associated with the manufacture (A1-A3), transportation to site (A4), transportation away from site (C2) and end-of-life (C3/C4) of wasted components. Note deconstruction emissions (C1) associated with waste can be assumed to be zero as the wasted components are not being installed.

$$\boldsymbol{ECF_{A5w,i} = WF_i \times (ECF_{A13,i} + ECF_{A4,i} + ECF_{C2,i} + ECF_{C34,i})} \quad (11)$$

Where:

$\boldsymbol{ECF_{A5w,i}}$	= construction waste embodied carbon factor for *i^th^* component ($kgCO_2e/kg$)
$\boldsymbol{WF_i}$	= waste factor for i^{th} material given by equation (12)
$\boldsymbol{ECF_{A13,i}}$	= module A1 – A3 embodied carbon factor for i^{th} material ($kgCO_2e/kg$)
$\boldsymbol{ECF_{A4,i}}$	= transportation to site, embodied carbon factor for i^{th} material ($kgCO_2e/kg$)
$\boldsymbol{ECF_{C2,i}}$	= transportation away from site, embodied carbon factor for i^{th} material (kgCO2e/kg)
$\boldsymbol{ECF_{C34,i}}$	= waste processing and disposal emissions ($kgCO_2e/kg$)

$ECF_{A3w,i}$ embodied carbon factor includes carbon sequestration for any timber products wasted during construction, as module A5 also accounts for the end of life of timber products wasted in $ECF_{C34,i}$. As explained in Appendix D, sequestration should be included where end of life emissions are accounted for.

$$\boldsymbol{WF_i = \frac{WR_i}{1 - WR_i}} \quad (12)$$

Where:

$\boldsymbol{WR_i}$	= waste rate (proportion of the total quantity of *the* i^{th} component brought to site that ends up as waste during installation).

At early design stages, where the supply chain is not confirmed, the waste rate may be taken from similar product EPDs or as follows:

- Components requiring cutting to size on site: $WR_i = 15\%$
- Components not requiring cutting to size on site (including glass / IGUs): $WR_i = 3\%$

The default waste rates presented are intended to be broadly indicative and provide consistency to the assessments until a more detailed analysis of waste rates can be undertaken. Designers should note that the assumed waste rates are likely to not be appropriate for the following materials and components:

- Natural stone panels;
- Bricks and blocks;

For these products designers should consult with suppliers and contractors to identify an appropriate waste rate.

At later design stages, waste rates may be taken from product-specific EPDs. Alternatively, where a contractor is seeking to establish a waste rate, this may be evaluated from the difference between the quantity of component included within the designed facade and the quantity of component brought to site.

Where facades are assembled off-site, it is generally understood that less waste material is generated during the on-site installation. Albeit at the time of writing, no data has been identified to quantify the extent to which off-site assembly reduces site waste. **This methodology permits $ECF_{A5,w}$ to be taken as zero when $ECF_{A3,w}$ is applied within the assessment** consistent with section 3.5.2.2 of the RICS guidance for prefabricated units.

Site activities emissions

The emissions associated with on-site construction activities are accounted for within life cycle module A5a. These emissions can be estimated by monitoring on-site fuel use and electricity consumption.

For each site activity carbon emissions can be quantified by applying the relevant Fuel Carbon Factor (FCF) where:

$$EC_{A5a} = \sum_{s=1}^{Total} FCF_s \times FC \qquad (13)$$

Where:

EC_{A5a}	= embodied carbon emissions from construction activities ($kgCO_2e$)
FCF_s	= fuel carbon factor for fuel source ‘s’ ($kgCO_2e/kWh$ or $kgCO_2e/litre$)
FC	= fuel consumption (kWh or litre)

For fuel carbon factors, Designers should refer to current UK Government ‘*Greenhouse gas reporting: Conversion factors*’ (15) and/or reported electricity grid carbon factors Table 5. The table below highlights some typical fuel types and associated carbon factors, however site-specific fuel source data should be used where possible. These values correspond to energy usage in the UK. For other countries, appropriate sources of carbon conversion factors must be used.

Fuel Type	Fuel Carbon Factor, FCF
Diesel (average biofuel blend)	3.17 $kgCO_2e$/litre[1]
Diesel (100% mineral diesel)	3.33 $kgCO_2e$/litre[1]
Petrol (average biofuel blend)	2.78 $kgCO_2e$/litre[1]
Petrol (100% mineral diesel)	2.94 $kgCO_2e$/litre[1]
Electric Vehicles/plant	Refer to Grid Carbon Factor [2] ($kgCO_2e$/kWh)
Note: [1] Data based on BEIS GHG Conversion Factors 2022 (14) and includes well-to-tank emissions.	

Table 5 – Fuel source carbon factors

For each on-site activity the following recording template example can be followed:

Required Field	Comments
Installation activity	Description of facade installation activity
Plant/machinery	Description of plant used including fuel/power source etc.
Fuel/energy consumption	litres/kWh of consumption over full duration of activity. Note, where practice, fuel consumption may be measured over a representative time period and then scaled up to cover the full duration over which the activity takes place.

Table 6 – Example installation activity recording template

Alternatively, where project-specific data is unknown, typically prior to and during construction, emissions can be estimated based on previous similar project data. Alternatively, the RICS guidance (5) can be adopted which provides a rate of 1400 $kgCO_2e$/£100,000 construction cost for a whole building. This approach is presented in equation (14).

It should be noted that the RICS approach is a preliminary estimate and can lead to double counting of emissions where off-site assembly emissions for pre-fabricated facade systems are quantified in stages A1-A3.

$$EC_{A5a} = FC_{\%} \times CAEF \times \frac{PC}{100,000} \tag{14}$$

Where:

EC_{A5a} = embodied carbon emissions from construction activities ($kgCO_2e$)

PC = project cost (£).

$FC_{\%}$ = facade cost as a percentage of the project cost (%). Advise should be sought from the project Quantity Surveyor at an early stage.

$CAEF$ = whole building Construction Activities Emissions Factor of:

1400 ($kgCO_2e$/£100,000 of Project Cost) Reference: BRE Meeting Construction 2025 Targets – SMARTWaste KPI p.3, footnote 9 (16)

When comparing the benefits of on and off-site assembly for different facade systems a more detailed analysis of module A5 emissions is required than the simplified cost-based approach presented in equation (14). Factory and site will have different approaches to construction and fuel sources. For a detailed facade comparison of Module A5a it is recommended to further engage with manufacturers and contractors to gain a more accurate embodied carbon emission rate.

2.2.5. Inputs for module B1: use

The materials used within typical facade systems generally have a negligible contribution to module B1 emissions over the life cycle.

Concrete surfaces exposed to the atmosphere will absorb CO_2 over time through carbonation. This is estimated to account for up to 2.5% reabsorption of the CO_2e emitted in the product stage (modules A1–A3) (6). Most concrete manufacturers include an allowance for this in their EPDs. If using manufacturers' EPDs to quantify carbonation, designers should check the assumptions contained within the EPD to ensure they match the conditions of their project (e.g. check the study period and atmospheric exposure assumed). For further information on the contribution of carbonation refer to the IStructE guidance (6).

2.2.6. Inputs for module B2: maintenance

Module B2 considers the emissions associated with planned maintenance to the facade. It includes the product stage emissions (A1-A3) and transportation emissions (A4) of the components and equipment used in the maintenance works. Furthermore, it includes emissions resulting from the use of energy and water in cleaning operations. Limited data is available to facilitate the accurate assessment of all facade maintenance operations.

Designers may refer to EPDs and consult operational and maintenance manuals to guide the appraisal of module B2 emissions with reasoned judgement.

In most typical facades, glazing cleaning operations are likely to represent the most significant contribution to module B2 over the life cycle of the facade. For this reason, guidance is provided on the assessment of the contribution of glazing cleaning to module B2. Designers can adapt this method to suit non-glazed facade surface areas as necessary by adjusting assumptions where required.

Glazing cleaning emissions

A series of default emission factors for glazing cleaning have been presented below. These factors have been evaluated from a bottom-up assessment of the processes involved. Key assumptions have been presented in Table 7 and designers should take care to verify the assumptions are reasonable for any given project.

$$\boldsymbol{ECF_{B2} = CR \times F_{clean} \times RSP} \qquad (15)$$

Where:

$\boldsymbol{ECF_{B2}}$	= module B2 embodied carbon factor for glazing cleaning ($kgCO_2e/m^2$ glazing)
$\boldsymbol{CR}$	= cleaning rate (i.e. the number of times the glazing is cleaned each year) (cleans/year)
$\boldsymbol{RSP}$	= reference study period (years)
$\boldsymbol{F_{clean}}$	= glazing cleaning emissions factor ($kgCO_2e/m^2$ glazing per year)

Default glazing cleaning emission factors are presented in Table 7.

Access for cleaning	Glazing cleaning emissions factor
Via non-powered equipment (i.e. from ground level, or via roped access)	0.010 $kgCO_2e/m^2$ of glazing
Via water-fed pole	0.016 $kgCO_2e/m^2$ of glazing [1]
Via Mobile Elevated Working Platform (MEWP)	0.106 $kgCO_2e/m^2$ of glazing [2]
Via Building Maintenance Unit (BMU)	0.015 $kgCO_2e/m^2$ of glazing [3]
Key assumptions: [1] Assumes small pump powered from diesel engine and transported 15km to project location. [2] Assumes diesel powered MEWP transported 15km to project location. [3] Assumes electrically powered BMU. The factor presented does not include the embodied carbon emissions associated with the manufacture and supply of the BMU product. All scenarios assume 0.2 litres of water use and 0.01 litres of detergent use per m^2 of glazing in accordance in BS EN 17074. The factors presented assume that the transportation of persons to site for the purpose of maintenance are excluded. This assumption is consistent with the approach documented in BS EN 15978 for Module A4.	

Table 7 - Default glazing cleaning emissions factors

Building Maintenance Units (BMU) are typically powered from the building's electric supply, and designers should take care to ensure the emission estimations are accounted for and coordinated with other parties on the project. Where the emissions to drive BMU operation is reported elsewhere by another party, designers should note this and assume a glazing emission factor based on 'non-powered equipment'.

Where the emissions associated with the manufacture and supply of the BMU are being assessed as part of the scope of assessment, designers should make clear if such emissions are reported separately, or as part of, the facade system results presented.

2.2.7. Inputs for module B3: repair

Module B3 considers the emissions associated with the repair of unpredicted damage to facade systems that occur outside of the maintenance regime. At the time of writing very little data exists with which to quantify module B3 emissions, moreover it is anticipated that the emissions will have a limited contribution to the total embodied carbon of facade systems.

Designers wishing to account for module B3 will need to quantify and document the extent of repairs assumed. In assessing the emissions associated with such repairs, designers should consider:

- The product stage (A1 – A3) and transportation (A4) emissions associated with new components required for the repair;
- The transportation (C2) and end-of-life (C3 – C4) emissions associated with the replaced components;
- Emissions associated with the required access to undertake repairs.

Further guidance on the definition of module B3 is provided in the CWCT guide; *life cycle modules explained* (12).

2.2.8. Inputs for modules B4: replacement

Module B4 considers the emissions associated with the planned replacement of facade components over the life of the building. This includes the production of the replaced components, transportation of replaced components, the replacement process, losses due to waste, end of life scenario of the removed components.

The emissions factor for module B4 is calculated by multiplying the emissions associated with the relevant modules of stages A – C of each material with the number of times it is to be replaced. Designers should take care to ensure a practical replacement strategy is viable on the project and appropriately captured within relevant O&M information.

Designers should be aware that module B4 assumes a 'like-for-like' replacement of components. Equation (16) implicitly assumes the embodied carbon (A-C) of the replacement component is equal in magnitude to the component being replaced. Albeit future efforts of the industry are forecast to reduce the embodied carbon of facade components, the degree of which is uncertain, the 'like-for-like' assumption is adopted to provide a consistent approach to the LCA. This approach is in accordance with the Greater London Authority *Whole Life cycle Carbon Assessment* guidance (17).

Further guidance on the definition of module B4 is provided in the CWCT guide; *life cycle modules explained* (12).

$$\boldsymbol{ECF_{B4,i}} = \left\lceil \frac{\boldsymbol{RSP}}{\boldsymbol{CL_i}} - \boldsymbol{1} \right\rceil \times (\boldsymbol{ECF_{A13,i}} + \boldsymbol{ECF_{A2,F,i}} + \boldsymbol{ECF_{A3w,i}} + \boldsymbol{ECF_{A3,FAB,i}} + \boldsymbol{ECF_{A4,i}} + \boldsymbol{ECF_{A5w,i}} + \boldsymbol{ECF_{C2,i}} + \boldsymbol{ECF_{C34,i}}) \quad (16)$$

Where:

$\boldsymbol{ECF_{B4,i}}$	= replacement emissions for i^{th} material ($kgCO_2e/kg$)
$\boldsymbol{RSP}$	= asset reference study period (years). Refer to section 2.2.8
$\boldsymbol{CL_i}$	= component lifespan (years) for i^{th} material. Refer to section 2.2.8
$\boldsymbol{ECF_{A13,i}}$	= embodied carbon factor for modules A1 – A3 for the i^{th} replacement material ($kgCO_2e/kg$)
$\boldsymbol{ECF_{A2,F,i}}$	= transportation to factory module $A2_F$ embodied carbon factor for i^{th} material ($kgCO_2e/kg$)
$\boldsymbol{ECF_{A3w,i}}$	= embodied carbon factor for module A3w for the i^{th} replacement material ($kgCO_2e/kg$)
$\boldsymbol{ECF_{A3,FAB,i}}$	= off-site fabrication emissions factor for the i^{th} component ($kgCO_2e/kg$)
$\boldsymbol{ECF_{A4,i}}$	= embodied carbon factor for module A4 for the i^{th} replacement material ($kgCO_2e/kg$)
$\boldsymbol{ECF_{A5w,i}}$	= embodied carbon factor for module A5w for the i^{th} replacement material ($kgCO_2e/kg$)
$\boldsymbol{ECF_{C2,i}}$	= embodied carbon factor for module C2 for the i^{th} replaced material ($kgCO_2e/kg$)
$\boldsymbol{ECF_{C34,i}}$	= embodied carbon factor for modules C3 – C4 for the i^{th} replaced material ($kgCO_2e/kg$)

Designers should note parameters $ECF_{A2,F,i}$, $ECF_{A3,W,i}$, $ECF_{A3,FAB,i}$ may not always be applicable to the facade component or system under assessment, refer to section 1.7.

Note:

$\left\lceil \frac{RSP}{CL_i} - 1 \right\rceil$ means round up the value of $(RSP/CL_i)-1$ to the next integer.

Designers should note the following clause from BS EN 15978:2011 9.3.3 *"If, after the last scheduled replacement of a product, the remaining service life of the building is short in proportion to the estimated service life of the installed product, the actual likelihood of this scheduled replacement should be taken into account. The consideration of the likelihood of the replacement shall take into account the required technical and functional performance for the product."*
Where adjustments to this end are made, these assumptions should be clearly reported within the assessment.

Reference study period

In accordance with RICS guide (5), the Reference Study Period (RSP) of an assessment is fixed to enable comparability between the results between different projects. The RSP is intended to:

- Be broadly representative of typical required service lives of the different building types;
- Allow for a sufficient period of time for the property to undergo wear and tear and specifically the replacement cycles of major building components and systems; and

- Stretch across a time period in the future that is reasonably predictable.

The RSP should be taken as follows:

- 60 years for domestic projects;
- 60 years for non-domestic projects;
- 120 years for infrastructure projects.

Where the required service life of a project varies significantly from the mandatory RSP presented above (i.e. temporary structures), the embodied carbon results may be additionally assessed against a RSP equal to the required service life of the project.

Component lifespan

A component lifespan shall be defined for each component of a given facade system. The component lifespan shall represent the anticipated time in service of the component.

The component lifespan should be based on the reference service life (RSL) of the product, typically provided within the EPD. Designers should be aware this figure may require modification to suit the specific in-use conditions of the project (i.e. the same component will have a varying lifespan dependant on the in-use environment). For detailed guidance on the assessment of RSL of products refer to BS ISO 15868-1 (18).

Where service life is not known, it is recommended that guidance from the CWCT Standard for Systemised Building Envelopes (19) is followed where primary facade components are expected to have a service life not less than the design life of the facade system, and secondary facade components are expected to have a service life less than the design life of the facade system. Examples of primary and secondary facade components are provided in Table 8. Further guidance to inform the selection of an appropriate RSL may be found in Annex D of BS 7543 (20).

Primary Component	Secondary Component
Framing components, their fixings and brackets	Insulated glazed unit (IGU)
Insulation	Window and door equipment
Vapour barriers than cannot be removed without dismantle of the envelope system	Accessible gaskets and sealants
Flashings, gutters, copings and similar metal weathering elements	Exposed finishes to components
Sealants and gaskets which are concealed within the system and which cannot be inspected and replaced without dismantling the envelope system	Internal linings

Table 8 – Examples of primary and secondary facade components

Designers should ensure the design and detailing of the facade permits the replacement of secondary components without replacement of primary components.

2.2.9. Inputs for module B5: refurbishment

Module B5 considers the emissions associated with a planned major change to the building envelope known at the time of the assessment but not actually being undertaken as part of the works.

The RICS guidance defines refurbishment as *"a planned alteration or improvement to the physical characteristics of the building in order for it to cater for the desired future function identified and quantified at the outset. This would typically involve a predetermined change of use at a point during* *the service life of the project, as well as a sizeable amount of works to several parts of the building."* (5)

Further guidance on the definition of module B5 is provided in the CWCT guide; *life cycle modules explained* (12).

Module B5 must take into account carbon emissions associated with the components used within the refurbishment works. The minimum scope of life cycle modules should align with that presented in section 2.1.1.

2.2.10. Inputs for module C1: deconstruction / demolition

Emissions associated with the deconstruction and demolition of facades are accounted for within module C1. This should include all on-site based activities that are required to dismantle, deconstruct and/or demolish the facade.

C1 emissions are accounted for through provision of embodied carbon factor, $\boldsymbol{ECF_{C1}}$.

At the outset of facade designs, project-specific scenarios for the facade at the end-of-life should be evaluated to determine the optimal solution to mitigate emissions associated with any deconstruction or demolition required.

Design for disassembly strategies are encouraged to be integrated into designs where possible to minimise overall emissions associated with the end-of-life and facilitate the reuse of materials and components. Consideration should be given to how waste can be reduced, if components can be repurposed, and how to minimise energy consumption and activities required to disassemble a facade. Such strategies should be incorporated in drawings, specifications, O&Ms and as-built data to ensure requirements are well documented and accessible for future implementation. Evaluation of design for disassembly processes are also encouraged to be tested prior to construction as part of planned mock-ups and testing procured to validate the viability of disassembly strategies envisioned to mitigate emissions.

In the absence of project-specific deconstruction/demolition requirements, the average rate of **3.4 kgCO$_2$e/m^2 GIA** can be assumed in accordance with RICS PS guidance (5). **Unit conversion to kgCO$_2$e/m^2 FSA should be applied as appropriate depending on how results are being reported.** Refer to equation (17)**.**

$$\boldsymbol{ECF_{C1}} = \boldsymbol{FC_{\%}} \times \frac{\boldsymbol{3.4}}{\boldsymbol{FFF}} \tag{17}$$

Where:

$\boldsymbol{ECF_{C1}}$	= demolition emissions factor (Module C1) of 1m^2 of facade (kgCO$_2$e/m^2 FSA)
$\boldsymbol{FFF}$	= facade form factor (m^2 FSA /m^2 GIA)
$\boldsymbol{FC_{\%}}$	= facade cost as a percentage of the project cost (%). Advice should be sought from the project Quantity Surveyor at an early stage.

2.2.11. Inputs for module C2: waste / deconstruction transport

Module C2 considers the emissions arising from the transportation of the discarded product as part of the deconstruction and demolition of the building.

Module C2 emissions should be calculated on a project-specific basis, considering the project location and end-of-life (EoL) scenarios. Designers should take care when extracting results from EPDs to ensure the underpinning assumptions are representative of the assessment being undertaken. Where EPD data is used, the carbon values should be adjusted accordingly to fit the project-specific scenarios (selection of on-site or off-site reuse or recycling scenarios for the different items).

The assessor should develop suitable project-specific EoL scenarios at a building level as well as individual components level where relevant. Scenarios should be based on known precedent and current EoL practices. The EoL scenarios should be clearly stated and explained within the assessment report. In the absence of specific information, scenarios on the proportion of landfilling, reuse and/or recycling each item at the EoL should be developed according to current standard practice, and all carbon emissions associated with the transportation of materials to the appropriate disposal site must be included in C2, including any interim stations.

$$ECF_{C2,i} = \sum_{mode} \left[TD_{mode} \times \frac{TEF_{mode}}{1000} \right] \quad (18)$$

Where:

$ECF_{C2,i}$	= transportation to site, module C2 embodied carbon factor for i^{th} material ($kgCO_2e/kg$)
TD_{mode}	= transport distance for given mode of transport (km)
TEF_{mode}	= transport emissions factor for given mode of transport ($gCO_2e/km.kg$)
1000	= conversion from grammes to kilogrammes

The Transport Emissions Factors (TEF) can be obtained from the '*Greenhouse gas reporting: conversion factors'* document published annually by the Department for Business, Energy & Industrial Strategy (15). For transport in other countries, appropriate carbon conversion factors for those countries must be used. TEFs for the most current year available should be used in the calculation. The dataset gives TEFs based on type of vehicle, percentage of load and the transport distance. The appropriate type of vehicle and amount of load should be estimated based on the product or system mass to pick the most representative TEF.

Where the specific mode of transport is unknown at the time of assessment, Designers may assume TEF factors from Department for Business, Energy & Industrial Strategy 'Greenhouse gas reporting: conversion factors' guidance (15). Designers should **assume road transport based on an average diesel HGV with 50% load** (= 0.12145 $gCO_2e/kg.km$ in 2022) to account for the vehicles coming to the site empty and leaving with a full load.

The transport distance should be calculated based on the distance between the project site and the disposal site or recycling facility. When specific information is unavailable, default values may be used based on assumptions of EoL scenario. These assumptions must be updated to suit project-specific information as and when available. Default EoL transport scenarios for the UK are presented in Table 9.

In the absence of project-specific information, the default values for transport distance from the RICS guidance (reproduced in Table 4) may be used, based on an assumption of EoL scenarios and modes of transport.

EoL scenario	Transport distance[1]
Reused / recycled on site	No transport emissions
Reused / recycled elsewhere	Assumed to be transported locally (50km)
Landfill / incinerated	Average distance from the construction site to the two nearest landfill sites
Note: [1] Transport distances consistent with RICS guidance (5).	

Table 9– Default EoL transport scenarios for the UK

Where components are reused or recycled on site, the emissions associated with module C2 may be assumed to be zero ($ECF_{C2,i} = 0$).

2.2.12. Inputs for module C3: waste processing

Emissions associated with processing inorganic and organic waste materials and/or facade components intended for reuse, repurposing, or recycling purposes are accounted for within module C3. This is specific to waste processes after the materials/components have reached the end-of-life state and before they reach the 'end-of-waste' state as defined in EN 15978, where the materials would have undergone necessary treatment scenarios required to reach this state. After which, the materials are ready for reuse, repurposing or recycling. End-of-life scenarios should be based on realistic appraisals of the current industry standard at the time of the assessment.

C3 emissions are accounted for through provision of embodied carbon factor, $\boldsymbol{ECF_{C34,i}}$.

Waste processing emissions can typically be found in EPD data. However, designers should be aware that EPD figures must be modified to suit end-of-life scenarios and associated processes specific to materials/components of the project. Therefore, project-specific requirements for treating materials and components at the end-of-life must supersede relevant EPD where required (e.g. the same material may require more or less treatments dependent on the planned re-use strategy).

In the absence of project-specific end-of-life requirements or relevant EPD data for waste processing, default assumptions should be assumed where disposal emissions in module C4 should be used as provided in accordance with section 2.2.13.

2.2.13. Inputs for module C4: disposal

Emissions associated with disposal of materials and/or facade components are accounted for within module C4. This is specific to waste processes prior to and as a result of final disposal (e.g. landfilling or incineration) of materials/components that are not intended to be reused, repurposed, or recycled.

Any potential environmental benefits from disposal (e.g. landfill sites capturing CO_2 emissions) should be accounted for in module D.

C4 emissions are also accounted for through provision of embodied carbon factor, $\boldsymbol{ECF_{C34,i}}$.

Similar to module C3, designers should be aware that EPD figures reported for module C4 must be modified to suit end-of-life scenarios and associated processes specific to materials/components of the project. Therefore, project-specific requirements for pre-treating and disposing of materials and components at the end-of-life may supersede the relevant EPD carbon factors where required.

In the absence of project-specific end-of-life requirements or relevant EPD data for disposal, or if disposal is reported as '0' in EPD data, default assumptions should be assumed for different processes and types of waste as presented in Table 10 and in accordance with RICS PS guidance (5).

In the absence of organic waste incineration data, an emission factor assumption for timber incineration should be used for carbon sequestration transfer to the atmosphere (biogenic carbon transfer) following the guidance in Appendix D.

End-of-life scenario	Disposal process emissions factor ($ECF_{C34,i}$)
Disposal of inorganic waste	0.013 $kgCO_2e/kg$
Disposal of organic, bio-based waste	2.15 $kgCO_2e/kg$
Incineration of organic, bio-based waste (biogenic carbon transfer)	1.64 $kgCO_2e/kg$ Equal to or greater than the magnitude of sequestered carbon [1]
Metallic waste (93% recycled, 7% landfilled)	0.020 $kgCO_2e/kg$[2]
Notes: [1] waste in this category is assumed as timber originating from a sustainable source. Refer to Appendix D for carbon sequestration and biogenic carbon transfer default assumption and requirements. [2] This end-of-life scenario for metallic waste is a weighted average of recycled and landfilled metals based on 2020 UK waste recovery statistics (Table 8) (21). The emissions factor associated with metallic recycling and landfilling have been taken from UK Government '*GHG conversion factors 2022*' (15).	

Table 10 – Default emission factors for waste processing and disposal

2.2.14. Inputs for module D: reuse, recovery and recycling potential

Module D quantifies the net environmental impacts, beneficial or detrimental, that occurs due to the reuse, recycling and energy recovery of materials and components beyond the boundary of the buildings' life cycle. For further guidance on the definition and boundary to module D refer to the *CWCT life cycle modules explained* guide (12).

Module D is accounted for through the provision of embodied carbon factor, $\boldsymbol{ECF_{D,i}}$.

$ECF_{D,i}$ is typically found in the LCA results reported in an EPD. In assessing module D emissions, the EPD author must make assumptions about the extent of reuse, recycling and energy recovery that can be accrued from the material or product at the end-of-life. These assumptions must be clearly documented within the EPD. Designers should take care to ensure these assumptions are valid and representative to the design under assessment. For example, where the design assumes a product can be directly reused at the end of its life, is the designer confident that the product can be disassembled? Are the necessary drawings and data recorded and stored effectively to enable future designers to justify and realise such reuse?

The module D contribution associated with the recovered materials or components (through reuse, recycling or incineration) requires designers to consider:

- The emissions saved insofar as the recovered product mitigates the demand for a new product (substituted products). The emissions associated with the substituted product should be based on a market average;
- The emissions associated with any processing works required to prepare the reused product (secondary product) for reuse.

$$\boldsymbol{ECF_{D,i} = ECF_{A13,secondary\ product} - ECF_{A13,substituted\ product}} \quad (19)$$

Where:

$\boldsymbol{ECF_{D,i}}$	= embodied carbon factor associated with Module D for i^{th} material ($kgCO_2e/kg$)
$\boldsymbol{ECF_{A13,secondary\ product}}$	= A1 – A3 embodied carbon factor ($kgCO_2e/kg$) associated with any processing works required to prepare the reused product (secondary product) for reuse
$\boldsymbol{ECF_{A13,substituted\ product}}$	= market average A1–A3 embodied carbon factor ($kgCO_2e/kg$) for the type of material or product in question. The product should have the same functional performance as the secondary product.

Module D is to be reported separately to stages A-C.

Where insufficient data exists to quantify module D, designers are encouraged to consider module D qualitatively to promote implementation of circular design strategies within projects. Where components are replaced over the Reference Study Period (RSP) of the assessment, designers should consider the contribution of replacement components to module D.

At this time, it is anticipated that further guidance on the assessment of module D will be provided in the future.

2.2.15. Carbon calculation scale-up factor

There are various types of uncertainties associated with facade designs that are acknowledged to be particularly more prevalent and inherent during early design stages. This will inevitably lead to unknowns that are difficult to quantify with certainty in an embodied carbon assessment.

At early design stages, it is important to also consider how such uncertainties, such as facade system complexity, can result in increased embodied carbon and how this can be avoided or reduced.

As the design progresses, the supply chain will become clearer, EPDs for products confirmed, complexity better understood, and construction and manufacturing documents produced, all of which can provide a greater level of certainty in an embodied carbon assessment. Therefore, as the design for the facade progresses, it is expected that such uncertainty in a design will reduce.

To address uncertainties identified during assessments undertaken at different stages of a design, it is strongly recommended that a carbon calculation scale-up factor, F, is applied to the reported results for stages A to C during early design stages.

Designers should note that the 'carbon calculation scale-up factor' described here is a separate parameter to the 'material factor' described in section 1.6.2.

A carbon calculation scale-up factor can be used to represent one or more types of uncertainties identified in a design, which must be reported within the assessment. A carbon calculation scale-up factor can be derived from reference to precedent studies, consultation with different manufactures, or from other types of analyses that must be reported with assumptions to support use of any carbon calculation scale-up factor applied to results.

The magnitude of the carbon calculation scale-up factor may be reduced through the design process to reflect changes in the level of uncertainty. Applying a lower carbon calculation scale-up factor than what was previously used at an earlier stage must be supported with data detailing why this can be achieved (e.g. appointed fabricator with a verified EPD, or a more simplified facade form). **At the construction stage when the supply chain is known, it is anticipated that a carbon calculation scale-up factor will no longer be required.**

Designers are strongly encouraged to identify, even qualitatively, any potential uncertainties in projects which create difficulties in accurately quantifying embodied carbon when carrying out an assessment at different stages of a project. These items identified are to be communicated to clients and the wider project team as necessary for coordination. These items are also to be reported with the results of an assessment, including how the carbon calculation scale-up factor was derived for application in an assessment to address each item identified.

By identifying these items during different stages of a design and assessment, it provides an opportunity to track them and ensure efforts are being made to revisit the design to refine it accordingly. Ultimately by doing so, it can bring more transparency and certainty to the assessment, improve potential for reduced emissions, and allow for a reduction in carbon calculation scale-up factors applied at later stages.

Some examples of such uncertainties in a design and assessment include:

- **Manufacturer EPD variations:**

  Prior to confirming the supply chain for the facade, the embodied carbon factor for the same or similar product can differ between supplier EPDs. This could result in potentially higher overall emissions calculated if potential variation is not considered at an early stage. Moreover, in accordance with BS EN 15804 section 6.3.6 (11), it should be recognised that the results reported within EPDs shall be within 5% of the true value for the product reported.

- **Bespoke elements:**
  For bespoke facade elements and finishes, an EPD is unlikely to be available to provide accurate data on the embodied carbon emissions of the product during early stages of a design. Designers should reach out to potential suppliers to understand the likely impact of bespoke elements, and uncertainty in the emissions should be acknowledged in assessments.

- **Different facade systems:**
  A project may include multiple facade systems on one building where the level of uncertainty between the different assemblies can vary. For example, due to differences between the fabrication and installation processes required, or variation in material types and sources.

- **Complex elements:**
  The complexity associated with the shape and forming of facade elements can require additional emissions which can be difficult to assess in comparison to a more standard element. For example, this could result in more processing and materials required during fabrication leading to higher off-site emissions than those allowed for in the early-stage assessment.

- **Unconfirmed supply chain:**
  Until a specialist facade contractor is appointed, including the associated supply chain producing the facade, there will be uncertainty in design documents (e.g. drawings and product specifications) used for preliminary embodied carbon assessments. It is expected that this level of uncertainty is minimised when the contractor is appointed, and the design for construction is developed for use in embodied carbon assessments.

- **Multiple energy sources:**
  Materials and products used for a facade may be produced in multiple countries using different grid carbon factors from a range of different fuel sources. Exact fuel types and sources may not be known until the supply chain is confirmed.

- **Human error:**
  Off-site and on-site human error during fabrication and construction can lead to additional emissions. For example, because of more waste produced, errors during site installation requiring unanticipated modifications, or over-designed elements not anticipated for. Coordination with the design team and contractors can minimise this risk, however, the potential for human-error to occur and increase emissions should not be ignored.

- **Representative area:**
  Where a representative area (AKA 'bay study') is used to assess the embodied carbon of the whole facade (see section 2.3), the results will be limited by the extent to which the representative area is truly representative of the whole facade.

Due to lack of data on the influence of different uncertainties on facade embodied carbon at different design stages, this guide cannot currently advise on magnitude of carbon calculation scale-up factor to be applied. It is anticipated that future revisions to this document will provide further guidance for how to select and apply the appropriate factors to a calculation when more data becomes available.

Industry members are encouraged to reach out to the CWCT with embodied carbon assessment data for facades where this methodology has been applied so that this data can be considered when updating carbon calculation scale-up factors in the future.

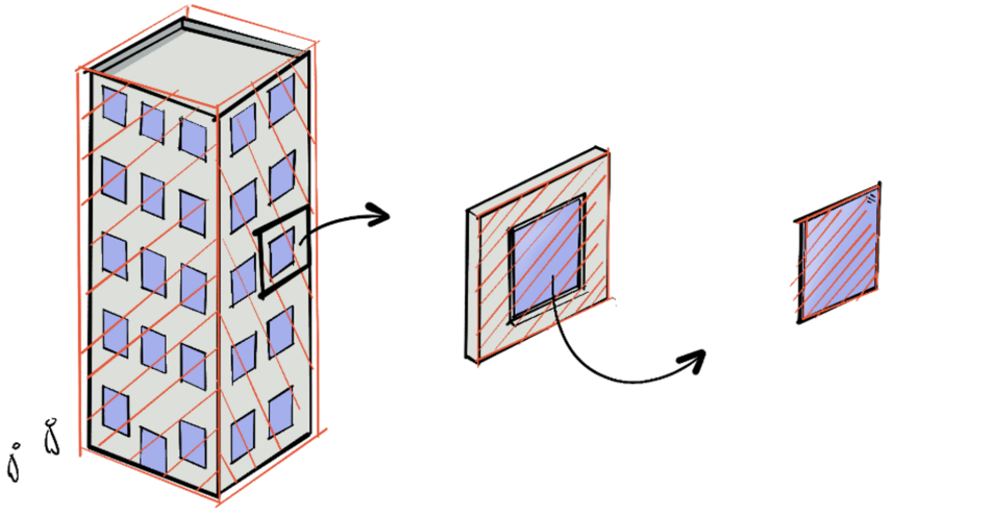
2.3. Process

This section summarises the process of the calculation of embodied carbon for different scopes of life-cycle modules. The formulas presented are applicable to both the simplified and full approaches presented in section 1.6.

In practice it is often more practical to assess the embodied carbon of a representative area of each facade system (i.e. a standard bay width, or repeating arrangement). The total embodied carbon of the project can then be assessed by multiplying the results of each facade system by the surface area of the building for which the system is applicable to. **For this reason, the equations presented in this section are formulated to assess the embodied carbon of a single facade system over a representative area (A).**

Where results are to be reported in units of 'kgCO_2e/m^2 FSA', simply divide the result by the representative area (A).

Figure 6 presents an illustration of the definitions for the areas referenced in the formulas below.



A_{total} Total facade surface area on the building (m^2)

A Representative facade surface area under assessment (m^2)

A_g Glazed surface area (m^2) within representative area assessed (A)

Figure 6 – Illustration of areas A_{total}, A, and A_g

2.3.1. Calculating modules A1 - A3

The key principle to calculating A1 - A3 emissions is to multiply the quantity of each component and material by the respective embodied carbon factors. Designers should note parameters $ECF_{A2,F,i}$, $ECF_{A3,W,i}$, $ECF_{A3,FAB,i}$ and $ECF_{A3,ASS}$ may not always be applicable to each facade component or system under assessment, refer to section 1.7.

$$EC_{A13} = \sum_{i=1}^{n}\left[Q_i(ECF_{A13,i} + ECF_{A2,F,i} + ECF_{A3,FAB,i} + ECF_{A3,W,i})\right] + (A \times ECF_{A3,ASS}) \tag{20}$$

Where:

EC_{A13}	= total embodied carbon for life cycle modules A1 – A3 ($kgCO_2e$)
Q_i	= quantity of i^{th} material (kg) within representative area assessed (A)
A	= representative area of facade assessed (m^2)
$ECF_{A13,i}$	= module A1 – A3 embodied carbon factor for i^{th} material ($kgCO_2e/kg$)
$ECF_{A3,W,i}$	= factory waste module $A3_W$ embodied carbon factor for i^{th} material ($kgCO_2e/kg$)
$ECF_{A2,F,i}$	= transportation to factory module $A2_F$ embodied carbon factor for i^{th} material ($kgCO_2e/kg$)
$ECF_{A3,ASS}$	= off-site assembly module emissions factor ($kgCO_2e/m^2$ FSA)
$ECF_{A3,FAB,i}$	= off-site fabrication emissions factor for the i^{th} component ($kgCO_2e/kg$)
$\sum_{i=1}^{n}$	= the summation of components from 1 to total number of components, n, in the facade system.

Sequestered carbon emissions should not be included within the results, when presenting results for life cycle stage A1-A3 or A1-A5 only. Sequestered carbon emissions may be reported separately alongside the results. Refer to Appendix D for further details.

2.3.2. Calculating modules A1 – A5

A1 – A5 emissions are calculated in the same way as A1 – A3 emissions, with additional factors for material transport to site and material wastage on site included.

Emissions associated with site activities, EC_{A5a}, are evaluated separate from the quantity of materials and therefore for sit outside the summation. EC_{A5a} , as calculated in accordance with section 2.2.4 Site activities emissions, represents the emissions of the total facade on the project and therefore has been scaled down by a factor of $\frac{A}{A_{total}}$ to reflect the proportion of the representative facade area under assessment (A).

$$EC_{A15} = EC_{A13} + EC_{A5a}\left(\frac{A}{A_{total}}\right) + \sum_{i=1}^{n}\left[Q_i(ECF_{A4,i} + ECF_{A5w,i})\right] \tag{21}$$

Where:

EC_{A15}	= total embodied carbon for life cycle modules A1 – A5 ($kgCO_2e$)
EC_{A13}	= total embodied carbon for life cycle modules A1 – A3 ($kgCO_2e$)
Q_i	= quantity of i^{th} material (kg) within representative area assessed (A)
$ECF_{A4,i}$	= transportation to site, module A4 embodied carbon factor for i^{th} material ($kgCO_2e/kg$)
$ECF_{A5w,i}$	= on-site construction waste (Module A5) embodied carbon factor for i^{th} material (kgCO2e/kg)
EC_{A5a}	= emissions due to construction site activities (Module A5) ($kgCO_2e$)
A	= representative area of facade assessed (m^2)
A_{total}	= total facade surface area on the building (m^2)
$\sum_{i=1}^{n}$	= the summation of components from 1 to total number of components, n, in the facade system.

2.3.3. Calculating stages A, B4 and C (minimum scope)

Emissions for modules A1 – A5, B4 and C1 – C4 reflect the minimum scope of assessment advised in section 2.1.1 of this document. Emissions associated with site activities, EC_{C1}, are evaluated separately from the quantity of materials and therefore sit outside the summation.

$$\boldsymbol{EC_{AC,min}} = \boldsymbol{F} \times \left[\boldsymbol{EC_{A15}} + \sum_{i=1}^{n} \left[\boldsymbol{Q_i} \left(\boldsymbol{ECF_{B4,i}} + \boldsymbol{ECF_{C2,i}} + \boldsymbol{ECF_{C34,i}} \right) \right] + \left(\boldsymbol{A} \times \boldsymbol{ECF_{C1}} \right) \right] \qquad (22)$$

Where:

$\boldsymbol{EC_{AC,min}}$	= total embodied carbon for life cycle modules A to C minimum scope ($kgCO_2e$)
$\boldsymbol{F}$	= carbon calculation scale-up factor (refer section 2.2.15)
$\boldsymbol{EC_{A15}}$	= total embodied carbon for life cycle modules A1 – A5 ($kgCO_2e$)
$\boldsymbol{Q_i}$	= quantity of i^{th} material (kg) within representative area assessed (A)
$\boldsymbol{ECF_{B4,i}}$	= module B4 embodied carbon factor for i^{th} material ($kgCO_2e/kg$)
$\boldsymbol{ECF_{C2,i}}$	= transportation away from site at end of life (Module C2) embodied carbon for the i^{th} material.
$\boldsymbol{ECF_{C34,i}}$	= waste processing and disposal (Module C3 and C4) embodied carbon for the i^{th} material.
$\boldsymbol{ECF_{C1}}$	= demolition emissions factor (Module C1) of $1m^2$ of facade ($kgCO_2e/m^2$ FSA)
$\boldsymbol{A}$	= representative area of facade assessed (m^2)
$\sum_{i=1}^{n}$	= the summation of components from 1 to total number of components in the facade system.

2.3.4. Calculating stages A to C

Emissions for stages A – C are evaluated with the same approach described for the minimum scope with addition of module B2. Aligned with the limitations highlighted in sections 2.2.5, 2.2.7, and 2.2.9 life cycle modules B1, B3 and B5 are not included in equation (23). As noted in section 2.2.6, B2 guidance is provided on the assessment of glazing cleaning. Designers can adapt the methodology for non-glazed areas by adjusting assumptions where required.

$$\boldsymbol{EC_{AC}} = \boldsymbol{F} \times \left[\boldsymbol{EC_{A15}} + \sum_{i=1}^{n} \left[\boldsymbol{Q_i} \left(\boldsymbol{ECF_{B4,i}} + \boldsymbol{ECF_{C2,i}} + \boldsymbol{ECF_{C34,i}} \right) \right] + \left(\boldsymbol{A_g} \times \boldsymbol{ECF_{B2}} \right) + \left(\boldsymbol{A} \times \boldsymbol{ECF_{C1}} \right) \right] \qquad (23)$$

Where:

$\boldsymbol{EC_{AC}}$	= total embodied carbon for life cycle modules A to C ($kgCO_2e$)
$\boldsymbol{F}$	= carbon calculation scale-up factor (refer to section 2.2.15)
$\boldsymbol{EC_{A15}}$	= total embodied carbon for life cycle modules A1 – A5 ($kgCO_2e$)
$\boldsymbol{Q_i}$	= quantity of i^{th} material (kg) within representative area assessed (A)
$\boldsymbol{ECF_{B4,i}}$	= Module B4 embodied carbon factor for i^{th} material ($kgCO_2e/kg$)
$\boldsymbol{ECF_{C2,i}}$	= transportation away from site at EoL (Module C2) embodied carbon for the i^{th} material.
$\boldsymbol{ECF_{C34,i}}$	= waste processing and disposal (Module C3 and C4) embodied carbon for the i^{th} material.
$\boldsymbol{A_g}$	= glazed surface area (m^2) within representative area assessed (A)
$\boldsymbol{ECF_{B2}}$	= module B2 embodied carbon factor for glazing cleaning ($kgCO_2e/m^2$ glazing)
$\boldsymbol{ECF_{C1}}$	= demolition emissions factor (Module C1) of $1m^2$ of facade ($kgCO_2e/m^2$ FSA)
$\boldsymbol{A}$	= representative area of facade assessed (m^2)
$\sum_{i=1}^{n}$	= the summation of components from 1 to total number of components, 'n', in the facade system.

2.3.5. Calculating module D

The embodied carbon associated with module D may be calculated from the summation of the product of the material or component quantity multiplied by the associated module D embodied carbon factor. Further guidance on the embodied carbon factor associated with Module D is presented in section 2.2.14.

$$\boldsymbol{EC_D} = \sum_{\boldsymbol{i=1}}^{\boldsymbol{n}} [\boldsymbol{Q_i} \times \boldsymbol{ECF_{D,i}}] \tag{24}$$

Where:

$\boldsymbol{EC_D}$	= total embodied carbon for life cycle module D ($kgCO_2e$)
$\boldsymbol{Q_i}$	= quantity of i^{th} material (kg) within representative area assessed (A)
$\boldsymbol{ECF_{D,i}}$	= embodied carbon factor associated with Module D for i^{th} material ($kgCO_2e/kg$)
$\sum_{\boldsymbol{i=1}}^{\boldsymbol{n}}$	= the summation of components from 1 to total number of components, ‘n’, in the facade system.

2.4. Outputs

Reporting project embodied carbon data to a publicly accessible database is vital to enable the development of benchmarks that can be used to inform embodied carbon targets and improve industry understanding of embodied carbon in the built environment. In the UK, the Built Environment Carbon Database (BECD) is being developed to capture industry-wide project carbon data. The BECD is due for launch in 2022 (22) and designers are encouraged to contribute.

2.4.1. Report requirements

The embodied carbon assessment report should include, but not be limited to, the following:

- Name of the assessor;
- Date of assessment;
- Name of the building/project;
- Type of building or project (i.e. office, residential, multi-use and new-build / refurbishment);
- Client for whom the assessment is being undertaken;
- Assessment methodology (referenced standards and guides);
- RIBA Workstage at the time of the assessment;
- Reference to any project embodied carbon targets where applicable;
- Description of the 'object of assessment' (refer to section 2.4.2) including notable limitations;
- List of indicators assessed. The scope of this guidance principally concerns only the Global Warming Potential (GWP) indicator measured in units $kgCO_2e$. Other indicators exist and can be found in BS EN 15978, Section 11 (1);
- List of modules assessed. If a module is excluded, the module shall be stated as 'MNA' (module not assessed);
- Clarification of assumptions, boundaries and scenarios used in the assessment, including highlighting significant changes from previous assessments;
- Identify any known areas of uncertainty within the assessments (refer to section 2.2.15);
- Schedule of components, component lifespan and embodied carbon factor data source assumed within each facade system;
- State if any material factor or carbon calculation scale-up factor has been included within the assessment;
- Reference to the information from which the material and component quantities have been derived;
- Results of assessment (refer to section 2.4.3).

Where the assessment is being undertaken during the design phase, the report should also include:

- Actions taken to reduce embodied carbon emissions and emission reductions achieved;
- Opportunities to further reduce the embodied carbon emissions.

Where the assessment is being as a record of the as-built assessment, the report should also include:

- Reference to, or inclusion of, as-built information used to inform the assessment.

2.4.2. Object of assessment

The report shall describe the ‘object of assessment’. This should include:

- Short description of the facade systems considered within the scope of the assessment;
- Identification of areas of the building envelope not considered within the scope of assessment;
- ‘Functional equivalent’ of each facade system to form the basis of comparison between assessments (see section 2.4.2);
- Reference Study Period (RSP).

Designers may include sketches and drawings of facade systems within the report to support the communication of the object of assessment.

Functional equivalent

The ‘functional equivalent’ is a representation of the required technical characteristics and functionalities of the facade system. It is the means by which the characteristics of the facade system are rationalised into a minimum description and forms the basis for comparison between assessments. **As a minimum the functional equivalent of a given facade system should include the definition of the following characteristics:**

- Design service life of the facade system (years).
- Floor-to-floor height (m).
- Area-weighted U-value (W/m^2K) and y-value (W/m^2K) if applicable.
- Peak characteristic wind load used in the design (kPa).

2.4.3. Presenting results

The results of the assessment shall be presented in the format presented in Appendix A.

Normalising results

The embodied carbon results reported shall be normalised to enable more consistent benchmarking between projects. The results should be normalised as follows:

- **By the Gross Internal Area in units *$kgCO_2e/m^2$ GIA.*** These figures will typically be used to inform the wider building assessment;
- **By Facade Surface Area in units *$kgCO_2e/m^2$ FSA*.** These figures will facilitate the comparison and optioneering of the facade design;
- **In total: in units of $kgCO_2e$ or tCO_2e.** These figures present the total emissions of the object of assessment.

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Appendix A. Reporting results template

Project Title	*Project X*	**Date:**	*DD/MM/YYYY*	**Assessment Approach:**	*Precedent/Simplified/Full*
Project Type	*[Domestic, Non-domestic, Resi., etc.]*	**Project Location**	*London, UK*	**Prepared by:**	*Name*
Project Stage	*[RIBA Stage]*	**Project Cost**	*£TBC*	**Reviewed by:**	*Name*
GIA	*TBC m²*	**FSA**	*TBC m²*	**Facade Form Factor**	*[=FSA/GIA]*

Facade System	**Description**	**Facade Surface Area (m² FSA)**	**Embodied Carbon ($kgCO_2e/m^2$ FSA)**															**EC_{AC} ($kgCO_2e/m^2$ FSA)**	**F x EC_{AC} ($kgCO_2e/m^2$ FSA)[3]**
			PRODUCT[1]	**Stored biogenic carbon**	**CONSTRUCTION**		**USE**							**END OF LIFE**			**BEYOND**		
			A1-A3		**A4**	**A5**	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**	**C1**	**C2**	**C3/C4[2]**	**D**		
FS-01	*Example*	*100*	*257*	*0*	*10*	*20*	*MNA*	*MNA*	*MNA*	*50*	*MNA*	*MNA*	*MNA*	*1*	*1*	*8*	*MNA*	***347***	***381***
FS-02	*Example with timber*	*100*	*257*	*-100*	*10*	*20*	*MNA*	*MNA*	*MNA*	*50*	*MNA*			*1*	*1*	*108*	*MNA*	***347***	***381***

Embodied carbon per GIA[3]	EC_{AC} = *??? $kgCO_2e/m^2$ GIA*
	Stored biogenic carbon = ??? $kgCO_2e/m^2$ GIA
	EC_D = *??? $kgCO_2e/m^2$ GIA*
Total embodied carbon[3]	EC_{AC} = *??? tCO_2e*
	Stored biogenic carbon = ??? tCO_2e
	EC_D = *??? tCO_2e*

Note:

[1] Product stage emissions excluding stored biogenic carbon (refer to Appendix D).

[2] Module C4 includes carbon emissions or transfers of stored biogenic carbon (refer to Appendix D).

[3] Designers to make clear where a material uplift factor (section 1.6.2) and/or carbon calculation scale-up factor (section 2.2.15) have been applied.

Appendix B. Facade component checklist

The following tables provide a list of typical components associated with a range of facade systems. It is important to note that the tables below are presented as a guide to designers to prompt consideration for all the components in a given facade system. **These tables do not present an exhaustive list of components, and designers will need to consider whether other components and associated finishes, beyond those listed, are relevant to the facade system considered.**

For some facade typologies, specific processes are also included to account for off-site assembly emissions where applicable.

Components indicated against the Simplified Approach represent the minimum scope of material quantities that should be determined if the Simplified Approach is followed in accordance with section 1.6.2.

Legend:

EPDs may combine components highlighted in blue into one. Refer to footnotes for further guidance.

Masonry / Hand-Set Stone Cavity Wall

Component	Simple Approach
Bricks / blocks	✓
Mortar	✓
Restraint sub-structure and dead-load brackets (e.g wall ties and support angles)	✓
External thermal insulation	✓
Cavity trays	
Firestopping	
Cavity barriers	
Movement joints (sealant + backer rod)	
Breather and waterproofing membrane	✓
Internal plaster boards (if within scope)	✓
SFS frame / block or concrete support wall (if within scope)	✓
SFS internal thermal insulation (if within scope)	✓
Sheathing boards	✓
VCL membrane	✓
Flashing and capping profiles	
Fixing screws	
Weep vents	

Rainscreen

Component	Simple Approach
Cladding panel	✓
Cladding support subframe (rails and brackets)	✓
External thermal insulation	✓
Firestopping	
Cavity barriers	
Sheathing board	✓
Breather and waterproofing membrane	✓
Internal plaster boards (if within scope)	✓
SFS frame / block or concrete support wall (if within scope)	✓
SFS internal thermal insulation (if within scope)	✓
VCL membrane	✓
Bracket thermal breaks	
Fixing screws	
Sealants	
Flashing and capping profiles	

Precast

Component	Simple Approach
Precast concrete	✓
Facing material (e.g. stone, brick, terracotta etc).	✓
Thermal insulation	✓
Brackets (including cast-in elements within the facade scope)	✓
Lifting anchors	
Bracket thermal breaks	
Firestopping	
Panel sealant joints (sealant + backer rod)	
Internal plaster boards (if within scope)	✓
Internal lining frame / block or concrete support wall if applicable (if within scope)	✓
Internal lining thermal insulation (if within scope)	✓
Breather and waterproofing membrane	✓
VCL membrane	✓
Flashing and capping profiles	
Fixing screws	
Fixings for facing material to precast	
Factory assembly process (if applicable)	
Off-site panel assembly	✓

Curtain Walling[1]

Component	Simple Approach
Glazing unit[2]	✓
Spandrel insulation	✓
Spandrel back panel	✓
Spandrel front panel	✓
Mullion frame	✓
Transom frame	✓
Pressure plates	✓
Mullion/transom gaskets	
Mullion/transom edge spacers	
Mullion/transom thermal breaks	
Fins and pressure caps	✓
Brackets (including cast-in elements in the facade scope)	✓
Bracket thermal breaks	
Spigots (for unitised)	
Firestopping	
Acoustic sealing at compartment floor	
Flashing and capping profiles	
Fixing screws	
Sealants (include if structural glazed)	
Interface waterproofing membrane	
VCL membrane	✓
Factory assembly process (if applicable)	
Off-site system assembly (e.g. unitised curtain wall)	✓

Composite Panels

Component	Simple Approach
Thermal insulation	✓
Back panel	✓
Front panel	✓
Panel adhesive	
Flashing and capping profiles	✓
Brackets and support elements	✓
Bracket thermal breaks	
Gaskets	
Interface waterproofing membranes	
Fixing screws	
Factory assembly process (if applicable)	
Off-site panel assembly	✓

[1] If a curtain wall system EPD is being used, this may include the elements highlighted in blue. If an EPD is not used for the curtain wall system, calculate these elements individually to include in the LCA.
[2] If a curtain wall system EPD is being used, check if a glazing unit is included within the scope of the EPD to ensure it is not calculated twice in the LCA. If it is excluded in the EPD, calculate the glazing separately and include it in the LCA.

Render

Component	Simple Approach
Render layers	✓
Reinforcing mesh (if included)	✓
External thermal insulation	✓
Render and insulation fixings	
Render carrier boards	✓
Internal plaster boards (if within scope)	✓
Internal lining frame / block or concrete support wall (if within scope)	✓
Internal lining thermal insulation (if within scope)	✓
Sealant joints	
Flashing and capping profiles	
VCL membrane	✓
Firestopping	
Cavity barriers (if the render is a rainscreen)	
Brackets and support elements	✓

Window and Door Systems[3]

Component	Simple Approach
Glazing units[4]	✓
Frame	✓
Gaskets	
Hardware	
Frame thermal breaks	
Brackets and support elements	✓
Bracket thermal breaks	
Flashing and capping profiles	✓
Interface waterproofing membranes	
Fixing screws	
Factory assembly process (if applicable)	
Off-site system assembly	✓

[3] If a window or door system EPD is being used, this may include the elements highlighted in blue. If an EPD is not used for the window or door system, calculate these elements individually to include in the LCA.
[4] If a window or door system EPD is being used, check if a glazing unit is included within the scope of the EPD to ensure it is not calculated twice in the LCA. If it is excluded in the EPD, calculate the glazing separately in include it in the LCA.

Appendix C. Glazing embodied carbon methodology

This appendix presents a methodology for the assessment of embodied carbon within glazing build-ups. This appendix has been included because:

- The number of processes involved in making architectural glass causes the calculation of the embodied carbon to be complicated;
- To date, most EPDs declare the performance of a given glazing build-up with limited guidance on how variations can impact the embodied carbon value reported;
- Depending on the project characteristics, the embodied carbon of glazing may contribute a significant proportion of the overall facade embodied carbon.

Whilst undertaking the research for the preparation of this document, various EPDs from major European glass manufacturers were consulted (refer to section C.6 for details), and their data analysed to extrapolate average values that may be considered representative of the different products and processes for glazing. Due to the non-homogenous nature of the data set, and lack of data for some processes, it was not always possible to calculate average values. In such cases, data from only a single source has been used at the time of writing this guidance. When data was not available at all, this has been clearly stated where relevant.

The variability that exists between suppliers will be covered by the use of the carbon calculation scale-up factor described in the main methodology document (refer to section 2.2.15), while glass material quantities and processing uncertainty during early stage assessments are to be covered with the material factor (refer to section 1.6.2). Furthermore, since EPDs remain valid for a limited time scale, it is recognised that the embodied carbon factors provided in this document will need to be updated in the future.

Designers are encouraged to use the methodology presented in this appendix to explore the impact of different glazing build-ups. The results of the calculation shall be verified by a supplier EPD as soon as practical in the design process.

C.1. Architectural glass production

Glass used in architecture is the result of a number of production processes which give the end product the performance characteristics it requires to meet the project targets. The many requirements architectural glass is asked to fulfil (structural, thermal, safety, acoustic, solar, daylight, security, etc.) make its fabrication particularly elaborate.

Float glass is produced by melting the raw materials (high quality silica sand, soda ash, limestone, glass cullet, and others in small quantities) in a large furnace, and then ‘floating’ the molten glass onto a tin bath. The glass ribbon is then cooled down in a controlled atmosphere and at a controlled temperature (the ‘annealing’ process). CO_2 is produced during the heating process and in the glassmaking chemical process.

For glazing to attain the required thermal and solar properties, some glass panes need to be coated. A large number of coatings are available with different performance characteristics. The most widespread method of coating glass is called “Magnetronic sputtering”; it consists in depositing multiple thin transparent layers of metals and metal oxides on top of one another on the glass surface. The specific combination of layers allows controlling both light and heat entering and leaving buildings through the glazing.

The next step in production is glass processing, which depending on the specific requirements, will include a combination of the following: cutting and shaping, edge treatment, heat-treatment (toughening or heat-strengthening), printing, and laminating. Other special processes, such as glass bending, are also possible; these are typically carried out by specialist suppliers.

When glass processing is complete, a glass pane for non-insulating uses (e.g., glass balustrades, external screens, internal partitions, etc.) can be considered ready. However, for most architectural applications insulating glass units (IGUs) are required. For the assembly of IGUs, two or more panes of glass are bonded together at their edges using high performance spacers to create a cavity and special sealants to make such cavity impermeable to air and moisture. The cavity is usually infilled with a gas (typically argon) to improve the insulating properties of the unit.

It should be noted that while glass coating is most typically carried out by the flat glass manufacturers at the same production site, the rest of the processes are typically undertaken by other glass processors in their own factories.

The use of glass cullet in float glass manufacturing is very important because it contributes significantly to minimising the environmental impacts associated to the process by reducing emissions both directly (cullet was already decarbonated during the initial raw materials fusion), and indirectly (reducing energy by lowering the melting temperature). Cullet originates from waste within the flat glass manufacturing process (internal cullet), from the use of flat glass in the downstream production process (pre-consumer cullet), and as the result of recycling at the end of the service life of the final product (post-consumer cullet). Nearly all waste from the various phases of architectural glass manufacturing becomes cullet (internal and pre-consumer), which makes it a very efficient waste recovery process.

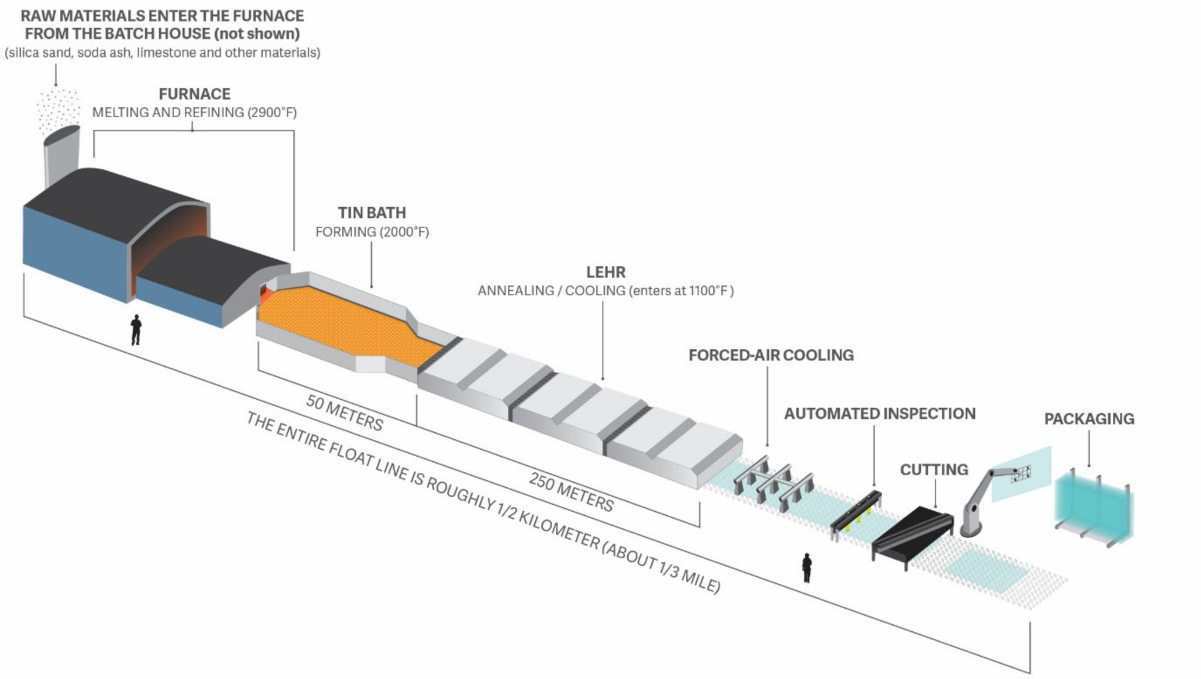

Figure 7 – Schematic of process for uncoated flat glass production (Images provided by Guardian® Glass)

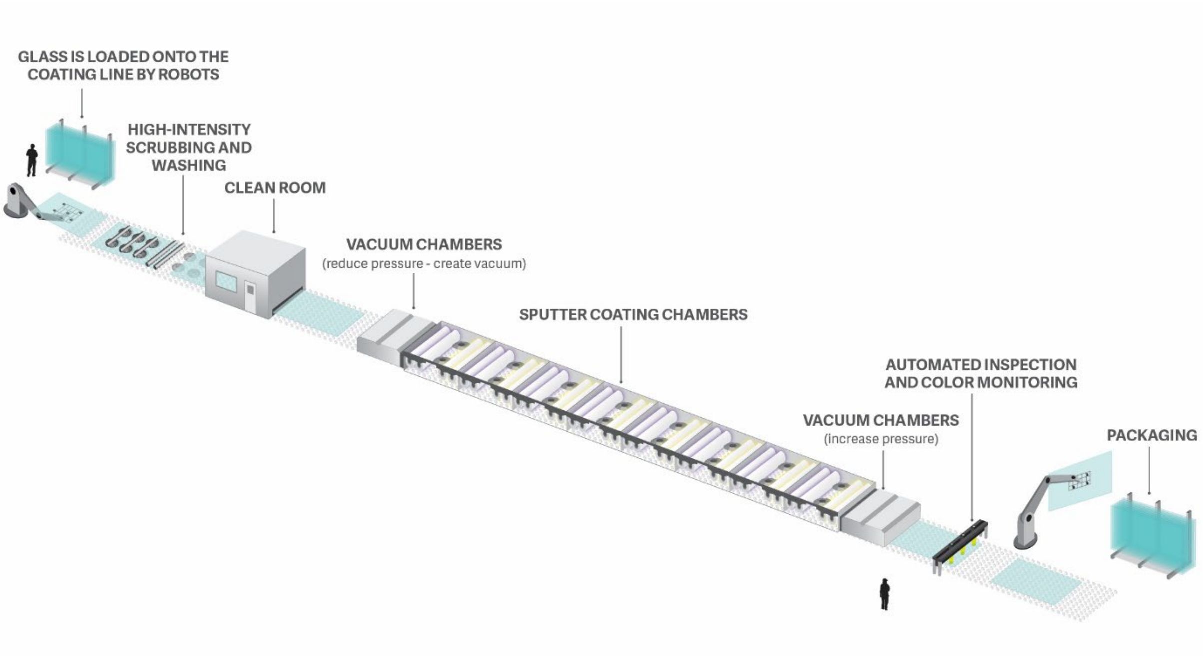

Figure 8 – Schematic of process for coated flat glass (Images provided by Guardian® Glass)

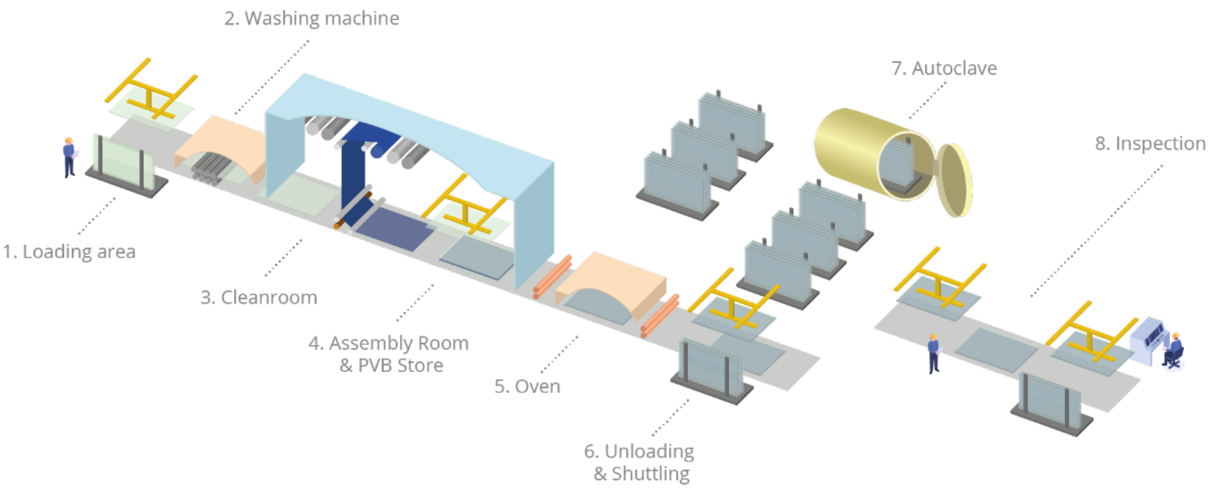

Figure 9 – Schematic of process for laminated safety glass production (Images provided by Guardian® Glass)

C.2. Methodology approach

Architectural glass is a complex product which undergoes a number of production steps. The calculation of embodied carbon of glazing needs to take into account all the different components and processes that will be involved in the creation of the specific glazing configuration for the project. The latter should be estimated at early design stages making conservative assumptions and refined in more detail as the design develops.

Designers are encouraged to use data from existing EPDs when these are available for a specific type of glass product and/or process. It is acknowledged that at present embodied carbon data is not available for every glass type and process; when values cannot be found in EPDs, advice shall be sought from glass manufacturers/suppliers. The source of the data used in the assessment should always be declared.

At early design stages, and in the absence of specific data, the embodied carbon of glazing solutions can be estimated using the methodology described in the grey boxes included in the following sections.

The life cycle modules addressed in this methodology are highlighted in red boxes in the image below in Figure 10 (taken from BS EN 17074 (23), *Product category rules for flat glass products*). With reference to the PCR, the mandatory modules (A1, A2, A3) and some of the optional modules (C3, C4, D) are covered in this appendix. For the remaining optional modules, and for additional guidance on all modules, reference shall be made to the main methodology document, where glass is considered in the context of whole facade systems rather than as a standalone element.

PRODUCT STAGE			CONSTRUCTION STAGE		USE STAGE							END-OF-LIFE STAGE				Benefits and loads beyond the system boundary
Raw Material supply (extraction, processing, recycled material)	Transport to manufacturer	Manufacture	Transport to building site	Installation in building	Use/ application	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	Deconstruction/ demolition	Transport to end-of-life	Waste processing for reuse, recovery or recycling	Disposal	Reuse, recovery or recycling potential
A1/A'1	A2/A'2	A3/A'3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D
M	M	M	O	O	O	O	NA	NA	NA	O	NA	O	O	O	O	O

M: mandatory, O: optional, NA: not applicable.

Figure 10 – Life cycle stages and modules addressed in this methodology (table taken from BS EN 17074 *(23)*, PCR for flat glass)

The various factors presented in the following sub-sections for different types of glass and for additional processes are summarised in the Table 11 below.

Life cycle modules	Glass production and processing	Section reference
A1-A3	Monolithic glass	Section C.3.1
A1-A3	Float glass	Section C.3.1.1
A1-A3	Performance coatings	Section C.3.1.2
A1-A3	Processing (edge-working, heat treatment, fritting)	Section 0
A1-A3	Laminated glass	Section C.3.2
A1-A3	IGUs	Section C.3.3
C3-C4	End-of-Life	Section C.4
D	Beyond system boundaries	Section C.5

Table 11 – Summary of glass embodied carbon factor inputs

C.3. Product stage (Modules A1-A3)

In this section a standard methodology for calculating the product stage embodied carbon of glazing elements is described. The sub-sections focus on the following typical glazing elements: monolithic glass, laminated glass, and IGUs.

The embodied carbon of a single glass pane shall include contributions corresponding to all relevant stages of glass production and processing. The embodied carbon of IGUs shall include contributions due to each glass pane, to the additional components (e.g., spacer bars), and to their assembly. At early design stages, if the build-up for the glass unit has not yet been calculated in detail, conservative assumptions with regards to glass thicknesses and potential processing shall be made.

Generally, glass processing and IGU assembly take place at different facilities compared to float glass production and glass coating. The emissions associated with travel between facilities used during the whole manufacturing process of the glazing should be accounted for in the total calculated emissions. Designers shall check that such impacts are included in the embodied carbon factors declared in EPDs for any glass product or process on the basis of average distances among processing facilities. This is also the assumption for the embodied carbon factors provided in the following paragraphs.

C.3.1. Monolithic glass

The embodied carbon associated with a monolithic glass pane shall be calculated as follows:

$$\boldsymbol{ECF_{A13,M} = ECF_{FL} + ECF_{C} + \sum_{i=0}^{n} ECF_{P,i}}$$

Where:

$\boldsymbol{ECF_{A13,M}}$	= Module A1–A3 embodied carbon factor of monolithic glass ($kgCO_2e/m^2$)
$\boldsymbol{ECF_{FL}}$	= embodied carbon factor of the float glass ($kgCO_2e/m^2$)
$\boldsymbol{ECF_{C}}$	= embodied carbon factor related to the application a performance coating ($kgCO_2e/m^2$)
$\boldsymbol{ECF_{P,i}}$	= embodied carbon factor related to the i^{th} process applied to the glass pane ($kgCO_2e/m^2$)
$\boldsymbol{n}$	= number of processes applied to the glass pane

Refer to the following sub-sections for additional details on each element of the equation.

It is acknowledged that EPDs might present combined data for some of the above factors. This is acceptable as long as the assumptions made and component data in the chosen EPD are declared, and the calculations carried out accordingly.

C.3.1.1. Float glass

The embodied carbon factor of float glass shall be derived from the EPD of a relevant monolithic glass product and for the specific thickness of the glass as designed. If at the point of undertaking the assessment, specific glass calculations are not available, a conservative assumption shall be made for the thickness of the glass pane.

The embodied carbon factor will depend on the specific type of glass chosen, such as mid-iron (now considered the industry standard), low-iron, or others. While some glass manufacturers provide individual values for each product, others provide only average values for the whole range of their products.

At early design stages, and in the absence of specific data, the embodied carbon factor of float glass can be estimated using the following equation:

$$\boldsymbol{ECF_{FL} = t \times ECF_{FL,t}}$$

Where:

$\boldsymbol{ECF_{FL}}$ = embodied carbon factor of float glass ($kgCO_2e/m^2$)

$\boldsymbol{t}$ = thickness of the glass substrate as designed (mm)

$\boldsymbol{ECF_{FL,t}}$ = embodied carbon factor of float glass per unit thickness ($kgCO_2e/m^2/mm$)

For mid-iron glass $\boldsymbol{ECF_{FL,t} = 2.96}$ ($kgCO_2e/m^2/mm$)

For low-iron glass $\boldsymbol{ECF_{FL,t} = 3.16}$ * ($kgCO_2e/m^2/mm$)

* value taken from a single source, to be updated in the future if more data becomes available

C.3.1.2. Performance coatings

The embodied carbon related to the application of a performance coating on a float glass substrate shall be derived from the EPD of the relevant product. If the EPD provides values for specific thicknesses of coated glass rather than the uplift for the coating process, then this should be declared, and it will cover both ECF_{FL} and ECF_C.

It is acknowledged that while some glass manufacturers provide distinct values for low-e and solar control 'families' of products, others provide only average values for the whole range of their coatings. Furthermore, not all glass manufacturers make a distinction between mid-iron and low-iron substrates.

At early design stages, and in the absence of specific data, the embodied carbon related to the application of a performance coating can be assumed as follows:

For magnetronic coatings $\boldsymbol{ECF_C = 0.91}$ ($kgCO_2e/m^2$)

For other types of coating, advice from glass manufacturers shall be sought.

C.3.1.3. Processing

The embodied carbon related to a specific process applied to a float glass substrate shall be derived from the EPD of an appropriate product. If the EPD provides values for specific thicknesses of processed glass rather than the uplift for the specific process, then this should be declared, and it will cover both $\boldsymbol{ECF_{FL}}$ and $\boldsymbol{ECF_{P}}$.

At early design stages, and in the absence of specific data, the embodied carbon related to a specific glass process can be estimated using the following equation:

$$\boldsymbol{ECF_{P}} = (\boldsymbol{ECF_{P,f}} + \boldsymbol{t} \times \boldsymbol{ECF_{P,v}})$$

Where:

$\boldsymbol{ECF_{P}}$ = embodied carbon factor of the process ($kgCO_2e/m^2$)

$\boldsymbol{ECF_{P,f}}$ = fixed embodied carbon factor of the process ($kgCO_2e/m^2$)

$\boldsymbol{ECF_{P,v}}$ = variable embodied carbon factor of the process ($kgCO_2e/m^2/mm$)

$\boldsymbol{t}$ = thickness of the glass substrate as designed (mm)

It should be noted that depending on the specific process, either the fixed or the variable impact could be zero.

In the following paragraphs some of the most common types of processing applied to architectural glass are explored, and guidance is provided in relation to the data currently available, if any. It should be noted that the specified values are likely to change in the future as glass manufacturers publish more up-to-date data.

Cutting to size and edge working

Currently there is no data available on the embodied carbon impact for the processes of cutting the glass to size and the edge-working of the panes. This has restricted the possibility to provide guidance. Designers / Assessors are encouraged speak to glass manufacturers / suppliers to seek relevant information. Considering that these are basic processes which occur to some degree in the production of all architectural glass, we believe this to be a systematic error which will not influence the comparison between different options. Embodied carbon factor values will be added in future updates, if data becomes available.

Heat treatment

Current EPD data does not differentiate between toughened and heat strengthened glass. It is understood that the difference between the two types of heat treatment in terms of energy required is small, and it mainly relates to the quenching phase. In the future, and as more data becomes available, different values may be provided to further differentiate the two types of heat treatment.

At early design stages, and in the absence of specific data from suppliers, the following factors can be used for heat treated glass (toughening or heat strengthening):

For mid-iron glass $\boldsymbol{ECF_{P,f}} = \boldsymbol{2.79}$ ($kgCO_2e/m^2$)

$\boldsymbol{ECF_{P,v}} = \boldsymbol{0.47}$ ($kgCO_2e/m^2/mm$)

Heat Soak Testing (HST)

Currently there is no data available on the embodied carbon impact of heat soak testing of toughened glass. This has restricted the possibility to provide guidance within this document at this time. Designers are encouraged speak to glass manufacturers/suppliers to seek relevant information required for an assessment including HST toughened glass. **Designers must be aware of this limitation when comparing glass build-ups to understand the difference in embodied carbon impact.**

Ceramic Printing / Digital Printing / Lacquering / Etc.

There is limited or no up-to-date data on the embodied carbon impact of different printing / painting processes on glass. This has restricted the possibility to provide guidance. Designers should speak to glass manufacturers / suppliers to seek relevant information. **Designers must be aware of this limitation when comparing glass build-ups to understand the difference in embodied carbon impact.**

Rolled (Heat-treated) Bending

Currently there is no data available on the embodied carbon impact of rolled bending of glass. This has restricted the possibility to provide guidance. Designers should speak to curved glass processors to seek relevant information. However, considering that this method of glass bending is always coupled with heat-treatment, the influence of the latter shall be accounted for; this will likely constitute most of the energy (and hence carbon) involved in the rolled bending process.

Mould (Annealed) Bending

Currently there is no data available on the embodied carbon impact of mould bending glass, a process which involves heating up the glass until it becomes soft enough to slump into a mould and then cooling it slowly. This has restricted the possibility to provide guidance. Designers should speak to curved glass processors to seek relevant information. **Designers must be aware of this limitation when comparing glass build-ups to understand the difference in embodied carbon impact.**

C.3.2. Laminated glass

The embodied carbon factor of laminated glass shall be derived from the EPD of a relevant glass product and for the specific configuration of the glass as designed (thickness of panes, type, and number of interlayers). If it is not possible to source data from an EPD for the specific laminated glass configuration, the embodied carbon associated with a laminated glass pane shall be calculated as follows:

$$\boldsymbol{ECF_{A13,L}} = \sum_{\boldsymbol{i=0}}^{\boldsymbol{m}} \left(\boldsymbol{EC_{A13,M,i}}\right) + \boldsymbol{ECF_{LAM}} + \boldsymbol{z} \times \boldsymbol{ECF_{INT}}$$

Where:

$\boldsymbol{ECF_{A13,L}}$	= embodied carbon factor of the laminated glass pane ($kgCO_2e/m^2$)
$\boldsymbol{ECF_{A13,M,i}}$	= embodied carbon of the *i^th^* monolithic glass sheet ($kgCO_2e/m^2$)
$\boldsymbol{m}$	= number of monolithic glass sheets that are being laminated
$\boldsymbol{ECF_{LAM}}$	= embodied carbon factor of the lamination process ($kgCO_2e/m^2$)
$\boldsymbol{z}$	= number of interlayers used (assuming a 0.38 mm interlayer as the base unit)
$\boldsymbol{ECF_{INT}}$	= embodied carbon factor of each 0.38 mm interlayer ($kgCO_2e/m^2$)

At early design stages, and in the absence of specific data from suppliers, the following factors can be used for laminated glass:

$\boldsymbol{ECF_{LAM} = 0.50}$ (kgCO_2e/m^2)

$\boldsymbol{ECF_{INT} = 2.74}$ (kgCO_2e/m^2) for PVB interlayers

Currently there is no data available on the embodied carbon impact of other types of interlayers, including Sentry Glass, EVA, coloured interlayers, etc. This has restricted the possibility to provide guidance. Designers should speak to interlayer suppliers to seek relevant information.

Fire rated laminated glass

Depending on the project requirements, a special type of laminated glass may be necessary to achieve the specified fire rating. This typically consists of two sheets of toughened safety glass and a sealed cavity in-between filled with one or more transparent intumescent interlayers. When exposed to radiant heat and fire, the intumescent interlayer(s) expand as an opaque foam to protect the occupied spaces for a specific time frame.

The embodied carbon factor of fire-resistant laminated glass shall be derived from the EPD of a relevant product and for the specific configuration of the glass as dictated by the target fire-rating (thickness of panes, number of intumescent interlayers). Due to the large variation in the possible configurations that can achieve different fire performance ratings, and considering the limited amount of data available, it is not currently possible to provide a base method for calculating the embodied carbon associated with fire-resistant laminated glass. If it is not possible to source required data from an EPD for the specific fire-resistant laminated glass configuration, designers shall speak to fire-resistant glass manufacturers / suppliers to seek relevant information.

C.3.3. Insulating glass unit (IGU)

The embodied carbon associated with an insulating glass unit shall be calculated as follows:

$$\boldsymbol{ECF_{IGU} = \sum_{i=0}^{k}\left(ECF_{A13,i}\right) + ECF_{Assembly}}$$

Where:

$\boldsymbol{ECF_{IGU}}$	= the embodied carbon factor (A1-A3) of the assembled IGU (kgCO_2e/m^2)
$\boldsymbol{ECF_{A13,i}}$	= the embodied carbon factor for the i^{th} glass pane, either monolithic or laminated (kgCO_2e/m^2)
$\boldsymbol{k}$	= the number of panes of the IGU (e.g., $k=2$ for double glazing)
$\boldsymbol{ECF_{Assembly}}$	= the embodied carbon factor of the IGU assembly process (kgCO_2e/m^2)

The latter shall comprise the emissions associated with the energy used in the process of assembly the IGU, as well as the emissions associated with the manufacturing of ancillary components, such as spacers, sealants, etc.

At early design stages, and in the absence of specific data from suppliers, the following factors can be used for double and triple glazing units:

For a double glazed unit (DGU) $\boldsymbol{ECF_{Assembly} = 12}$ (kgCO_2e/m^2)

For a triple glazed unit (TGU) $\boldsymbol{ECF_{Assembly} = 24}$ (kgCO_2e/m^2)

C.4. End of life (Modules C3-C4)

Designers shall use relevant information from EPDs with regards to the processes required for waste processing and disposal of glass and their carbon impact, where this is available from suppliers / manufacturers.

Please refer also to BS EN 17074 ((23), Product category rules for flat glass products for guidance on end-of-life stages of glass.

C.5. Beyond system boundaries (Module D)

When evaluating the potential positive contribution of glass recycling, the designer shall:

- Make reference to a specific EPD, if relevant;
- Ensure a feasible disassembly strategy is established and documented in as-built information to recover glazing from the building;
- Make sure that the any assumptions made are in line with specific project assumptions with regards to glass recycling;
- Provide evidence of the glass recycling scheme being considered on the project, and how its benefits are to be accounted for.

Please refer also to Annex D of BS EN 17074 ((23), *Product category rules for flat glass products* for information on closed-loop recycling of glass, and to section 2.2.14 for general guidance on inputs for module D.

C.6. Glass EPDs consulted

The EPDs that were consulted to develop this appendix are listed below, grouped by glass manufacturer. The referenced EPDs are provided for transparency and their reference should not be considered as an endorsement by the CWCT.

Guardian Glass Europe

- EPD-GFEV-GB-19.2 – Uncoated flat glass, laminated safety glass and coated flat glass (published on 29/06/2021, valid until 29/06/2026)

Saint-Gobain Glass

- EPD S-P-00882 – Planiclear, clear float glass (published on 17/12/2021, valid until 29/09/2026)
- EPD S-P-00883 – Diamant, extra-clear glass (published on 17/12/2021, valid until 29/09/2026)
- EPD S-P-00884 – Parsol, body tinted glass (published on 17/12/2021, valid until 29/09/2026)
- EPD S-P-00926 – Magnetron coated glass on Planiclear & Diamant (published on 17/12/2021, valid until 14/12/2026)
- EPD S-P-00927 – Securit on Planiclear, on Diamant, on Parsol (published on 17/12/2021, valid until 14/12/2026)
- EPD S-P-00930 – Stadip Protect / Silence (published on 17/12/2021, valid until 29/09/2026)
- EPD S-P-00934 – Climalit, Double Glazing (published on 15/11/2016, valid until 15/11/2021 - expired)
- EPD S-P-00932 – Climaplus / Climalit Plus, High performance Double Glazing (published on 20/12/2016, valid until 15/09/2021 - expired)
- EPD S-P-00933 – Climatop, High performance Triple Glazing (published on 20/12/2016, valid until 15/09/2021 - expired)
- EPD S-P-03251 – Contraflam (published on 15/03/2021, valid until 15/03/2026)

AGC Glass Europe / Interpane

- Environmental and health product declaration: Planibel (published in May 2018, valid until May 2023)
- Environmental and health product declaration: Laminated Glass (published in May 2018, valid until May 2023)
- Environmental and health product declaration: Low-e magnetron coated glass (published in March 2019, valid until March 2024)
- Environmental and health product declaration: Solar control magnetron coated glass (published in March 2019, valid until March 2024)
- EPD-APG-GB-21.1 – Pyrobel and Pyrobel Light (published on 17/03/2021, valid until 17/03/2026)

Model EPDs developed by IFT Rosenheim

- M-EPD_FG_ESG_VSG_efin – Flat glass, toughened safety glass and laminated safety glass (published on 18/12/2017, valid until 18/12/2022)
- M-EPD_MIG_efin – Insulating glass units (IGUs), double and triple glass configurations (published on 18/12/2017, valid until 18/12/2022)

IGU EPDs published by glass processors

- EPD-Vidriera Arandina S.L.-100-EN – Insulating glass units (published on 15/12/2020, valid until 14/12/2025)
- EPD-ASTIGLAS S.L.-92-EN – Insulating glass units (published on 11/09/2020, valid until 10/09/2025)

Appendix D. Carbon sequestration in timber

D.1. Background

As with any other material, timber has production stage emissions. These include emissions resulting from the harvesting, drying, sawing and treatment processes of the timber manufacture.

As trees grow, carbon dioxide is removed from the atmosphere via photosynthesis, this is known as 'sequestration' of carbon. This carbon is stored in the timber until it is released at the end of life of the timber as gas (CO_2 and CH_4) either by burning or decomposition. It follows that, the use of timber in buildings can be thought of as a 'carbon sink', whereby the carbon is locked away for the duration of its life acting to delay the emission of the sequestered carbon. It is only reasonable to account for the benefits of sequestration if the trees harvested for the timber product are replanted as part of sustainably managed forest.

The term 'timber product' here refers to all construction materials derived from or including timber such as plywood, CLT, particleboard, etc. These materials all contain some amount of sequestered carbon. Carbon sequestration can be considered for any of these products provided that they are sourced from a sustainably managed forest. Note that sequestered carbon is released back into the atmosphere at end of life.

For further background information on this topic, readers are referred to W. Hawkins *Timber and carbon sequestration* article (24).

Note, sequestered carbon in timber is also referred to as "stored biogenic carbon".

D.2. Reporting requirements

There is contradictory guidance in the industry regarding when and where sequestered carbon should be accounted and reported within the building life cycle framework. Consistency in the reporting of timber sequestration is critical to the benchmarking between assessments and optioneering appraisals. To this end, this guide adopts the recommendations consistent with the IStructE *'How to calculate embodied carbon'* section 2.2.2 Module A3: Off-site wastage emissions (6).

Carbon sequestration should be considered within an embodied carbon calculation **provided that the timber or timber product originates from a sustainably managed forest with FSC or PEFC (or equivalent) certification and the scope of the calculation includes life cycle stages A to C.**

When stages A – C emissions are presented, carbon sequestration in timber should be accounted within life cycle modules A1-A3 and end-of-life emissions and biogenic carbon transfers should be considered in modules C3-C4. This allows for accuracy and consistency of reporting. Note that the negative emissions (sequestration) in modules A1-A3 will typically be offset by the positive emissions (release or transfer) in modules C3-C4 in the A-C total.

When A1-A3 or A1-A5 emissions are summed and presented alone, carbon sequestration should not be added to the sum.

The stored biogenic carbon can also be **presented alongside the total embodied carbon result for stages A-C as a separate figure to communicate the benefits associated with the biogenic storage.**

This guide does not recommend including the carbon sequestration when end-of-life emissions are not reported because this would typically result in a negative value for the A1 – A5 embodied carbon (i.e. showing a net extraction of carbon emissions from the atmosphere). This could allow designers to show that less efficient use of timber results in lower, i.e. a greater negative value of, embodied carbon. This must be avoided to prevent unnecessary use of resources.

It should be noted that unless the reuse of the timber product at the end-of-life can be guaranteed, life cycle modules C3 and C4 will account for the release of sequestered carbon back into the atmosphere and this will equal or exceed the magnitude of the sequestered carbon. If the timber is considered to be reused at the end-of-life stage, the stored biogenic carbon is considered to be transferred to the next life cycle. Hence, for consistency of reporting within the industry and to avoid double counting of emissions, 'biogenic carbon transfer' of magnitude equal to the sequestered carbon is reported in life cycle modules C3-C4. Refer to the IStructE guide section 2.2.2 Module A3: Off-site wastage emissions for more information on carbon transfer.

Designers should take care to understand where sequestered carbon is accounted for within the figures assumed from timber product EPDs. In some instances, this will require designers to discount the presented EPD figures to remove the carbon sequestration benefits from the product stage emissions.

In the absence of product specific data, **carbon sequestered can be assumed as -1.64 kgCO_2e/kg of timber.** This assumes the default values given in the RICS guidance (5) of carbon fraction of woody biomass = 50% and moisture content = 12%. **The end-of-life emission (C3-C4) can be assumed as 1.64 kgCO_2e/kg of timber (i.e. equal to the sequestered carbon).** This value is consistent with an assumed incinerations end-of-life scenario.