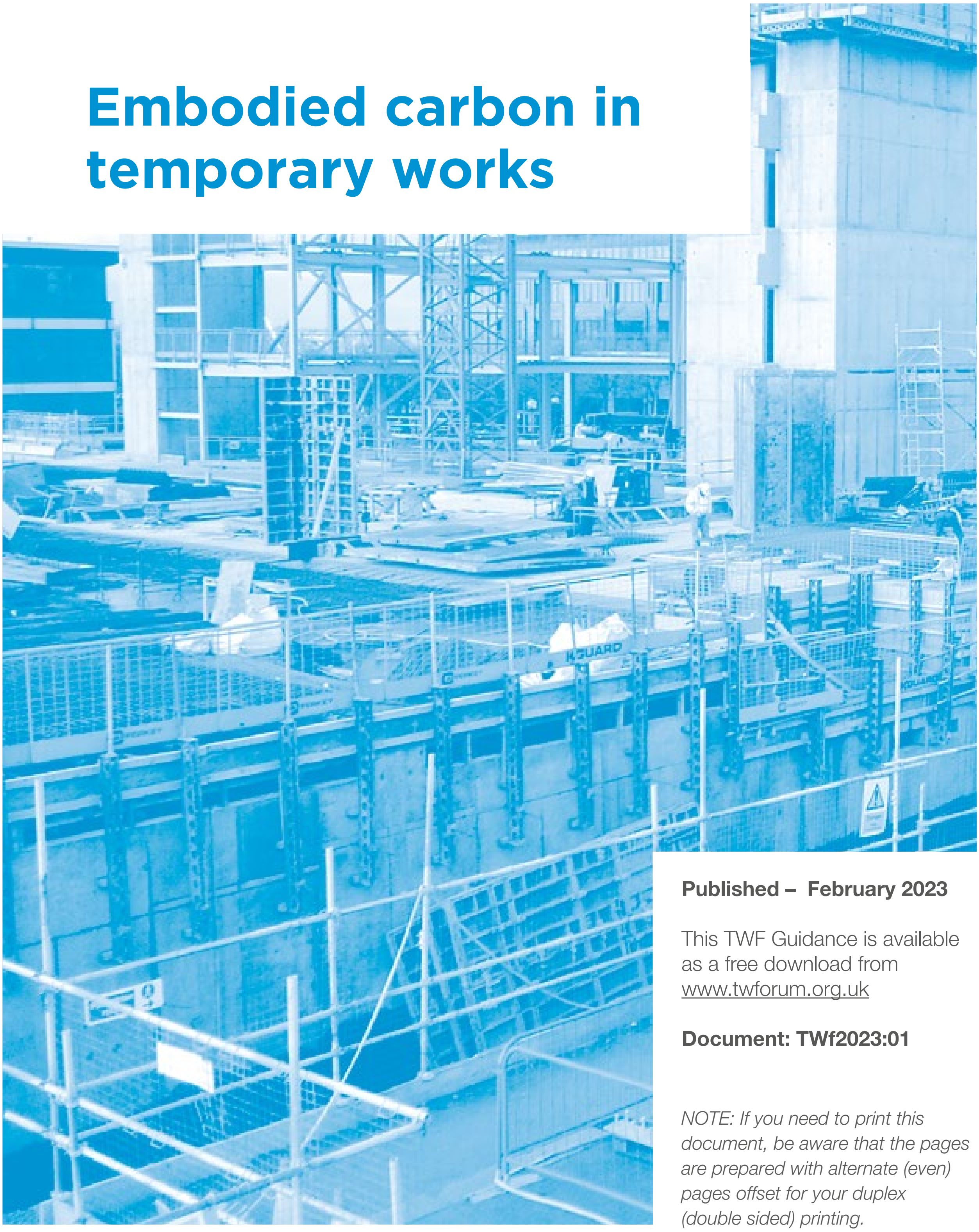
Embodied carbon in temporary works



Published – February 2023

This TWF Guidance is available as a free download from www.twforum.org.uk

Document: TWf2023:01

NOTE: If you need to print this document, be aware that the pages are prepared with alternate (even) pages offset for your duplex (double sided) printing.

Temporary Works forum

Members of the Working Party

This guidance has been prepared by Luke Winch (Balfour Beatty) and Sam Hurst (Costain). Editor: David Thomas (Temporary Works Forum).

Acknowledgement

The Temporary Works Forum (TWf) gratefully acknowledges the contribution made by the working group and contributors in the preparation of this guidance. In particular, thanks are due to the following:

Eleanor Lee	Tony Gee and Partners LLP
Fiona Radford	Kier Group
Jack Furlong	Kier Professional Services
Kevin McGinty	Tony Gee and Partners LLP
Rebecca Woodhouse	Tony Gee and Partners LLP

Synopsis

The construction industry is a heavy carbon emitter. Those working in it have the responsibility and opportunity to decarbonise. This extends to the full spectrum of the industry including those considering temporary works.

The purpose of this guidance is to assist those modelling carbon associated with temporary works (TW) to calculate and quantify subsequent reductions in embodied carbon. The guidance provides commentary on achieving this with consistency across the industry against a backdrop of a great many tools and methodologies for calculating embodied carbon. The tools and methods described in this guidance serve no purpose other than to inform decisions to decarbonise.

The quantification of embodied carbon points to the simple truth: we must use less material to progress to net zero.

Contents

To navigate to page - hover over an item below and ‘click’. Return to contents by clicking on the ‘Return to the contents’ at the bottom of every page.

1.0 Introduction

1.1 Background

The purpose of this guidance is to assist those modelling carbon associated with temporary works (TW) to calculate and quantify subsequent reductions in embodied carbon. As the need to calculate embodied carbon comes to the fore, it is almost certain to extend to 'temporary works' and this guidance provides commentary on achieving this with consistency across the industry against a backdrop of a great many tools and methodologies for calculating embodied carbon. These methods work to establish a baseline and for comparing solutions ('benchmarking') to allow for the management and reduction of embodied carbon with respect to temporary works.

Whilst this guidance draws on the methodology described in the IStructE's *How to calculate embodied carbon* [1.], the complementary information and principles described here may be applied to any methodology concerning temporary works.

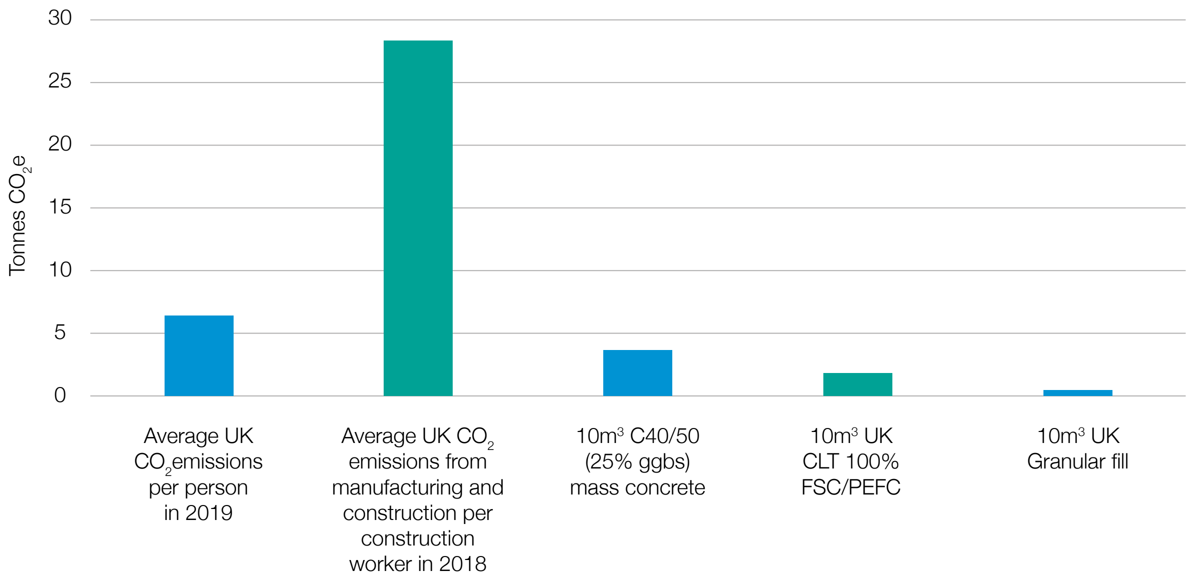


*Figure 1 - Opportunity for the Construction Industry to Decarbonise the UK**

* *Average UK CO_2e emissions per person in 2019 was calculated by dividing the total greenhouse gas emissions (CO_2e) by the total population. Data taken from the World Bank World Development Indicators [2.].*

Average UK CO_2e emissions from manufacturing and construction per construction worker in 2018 was calculated by dividing the Greenhouse gas emissions from manufacturing and construction (taken from the Climate Change Committee Sixth Carbon Budget [3.]) by the number of construction workers in the UK (taken from the Office of National Statistics JOBA5: Workforce jobs by region and industry [4.]).

The embodied carbon for each material was calculated using the following Embodied Carbon Factors (A-D assessment considered) taken from IStructE's How to calculate embodied carbon [1.]:

	A1-3 (kgCO2e/kg)	A4 (kgCO2e/kg)	A5 (kgCO2e/kg)	C2 (kgCO2e/kg)	C3-4 (kgCO2e/kg)	D (kgCO2e/kg)
C40/50 (25% GGBS) mass concrete	0.138	0.005	0	0.005	0.013	0
UK CLT 100% FSC/PEFC	0.25	0.161	0	0.005	1.662	-0.524
UK Granular fill	0.008	0.005	0	0.005	0.013	0

In 2019, the average CO_2e emissions per person in the UK was 6.58 tonnes CO_2e [2.]. Figure 1 represents the average CO_2e emissions for the manufacturing and construction industry per construction worker and the embodied carbon for 10m^3 of various materials. This illustrates two points:

1. Through their work, the average construction worker spends over 4 times the amount of CO_2e than a member of the general public. They have a far greater opportunity to decarbonise society in their professional lives rather than their personal lives. For key decision makers, this value is likely to be much higher.
2. It is not difficult to imagine that with regular savings in materials, the carbon saved would quickly outweigh the personal carbon footprint of the average person in the UK.

NOTE: The data taken from the Climate Change Committee Sixth Carbon Budget [3.] covers both the manufacturing and construction industry, so estimates for the carbon footprint for the average construction worker may be higher than the actual carbon footprint.

Manufacturing and construction is responsible for 12% of the UK total greenhouse gas emissions (66 Mt CO_2e) [3.] which signifies an unparalleled opportunity for those working in the industry to decarbonise society. The most significant and most immediate means of decarbonisation is through reduction in material consumption.

The most significant and most immediate means of decarbonisation is through reduction in material consumption.

1.2 Scope

The scope of this guide is summarised in Table 1.

1.3 Terms and Definitions

For the purposes of this document, the following terms and definitions apply.

1.3.1 Asset

Physical entity forming part of infrastructure that has potential or actual value to an organisation and its stakeholders.

NOTE: Taken from PAS 2080 [5.]. The term asset may be used to describe building and civil engineering works.

1.3.2 Carbon dioxide equivalent (CO_2e)

Unit for comparing the radiative forcing of a greenhouse gas to carbon dioxide.

NOTE: Taken from PAS 2080 [5.].

1.3.3 Construction works

Everything that is constructed or results from construction operations.

NOTE: Taken from BS EN 15978 [6.]. This covers both building and civil engineering works, and both structural and non-structural elements.

1.3.4 Environmental product declaration (EPD)

An EPD … provides quantified environmental information for a construction product or service on a harmonized and scientific basis . . . The purpose of an EPD in the construction sector is to provide the basis for assessing buildings and other construction works, and identifying those, which cause less stress to the environment.

NOTE: Definition taken from BS EN 15804:2012 [7.].

1.3.5 Greenhouse gases (GHGs)

Gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of infrared radiation emitted by the Earth's surface, the atmosphere, and clouds.

NOTE: Taken from PAS 2080 [5.]. Throughout this guidance, the term carbon is often used interchangeably with GHGs and CO_2e.

1.3.6 Temporary works

Temporary works can be described as providing an "engineered solution" that is used to support or protect either an existing structure or the permanent works during construction, or to support an item of plant or equipment, or the vertical sides or side-slopes of an excavation during construction operations on site or to provide access. It is used to control stability, strength, deflection, fatigue, geotechnical effects and hydraulic effects within defined limits.

NOTE: Taken from BS 5975: 2019 [8.].

Table 1 – Scope of this guidance

This guide is about . . .	It is not about . . .
Focusing on the measurement and reduction of embodied carbon associated with temporary works	Wider environmental issues
Providing salient and complimentary information to assist users to apply established methods specifically to temporary works	Wholesale reproduction of existing methodology/ available information or creating a new calculation methodology

1.4 Application

1.4.1 Embodied carbon

The general philosophy considered in this guidance is to assign carbon factors to material quantities for each life-cycle module to determine embodied carbon:

Embodied Carbon= Material quantity (kg) x Embodied carbon factor (ECF) (kgCO2/kg)

Broadly, material should be split into three categories, namely:

- **Single-use material**

  Requires the production of new materials.

  The overarching principle when considering the embodied carbon for single-use material is that all the carbon required to produce, transport, use and dispose of is attributed to the use of the material.

- **Finite reuse product**

  Materials that are reused a specified number of times before the material's 'End of Life' (EoL).

  The overarching principle when considering the embodied carbon for finite reusable material use is that the carbon required to produce, transport, use and dispose of material may be divided by the number of times the material is reused before it reaches its EoL.

- **High reuse/proprietary**

  Materials that exist already and have been used on other construction sites or newly-manufactured but to be used on other construction sites, e.g. scaffold tubes.

  The overarching principle when considering the embodied carbon for this material use is that as the material is reused a great number of times, the carbon required to produce and dispose of the material may be considered to be negligible at the point of use. Transport is considered as usual.

1.4.2 Life-cycle modules

Figure 6 in BS EN 15978 [6.] (see Figure 2) describes the asset 'life-cycle modules' to define the system boundary for the scope of carbon assessment.

1.5 Cut-off criteria

When considering the quantification of GHG emissions, reference should be made to PAS 2080 [5.] and, more specifically, Clause 7. This sets the boundaries for what is to be considered during carbon assessment and a key concept is the 'cut-off criteria' set out in Clause 7.1.3.3. It is recommended that the following extract is applied when measuring carbon:

"The total excluded input or output per module shall be a maximum of 5% of energy usage and mass; Expert judgement by the practitioner shall be used to determine compliance with these criteria"

Figure 6 – Display of modular information for the different stages of the building assessment

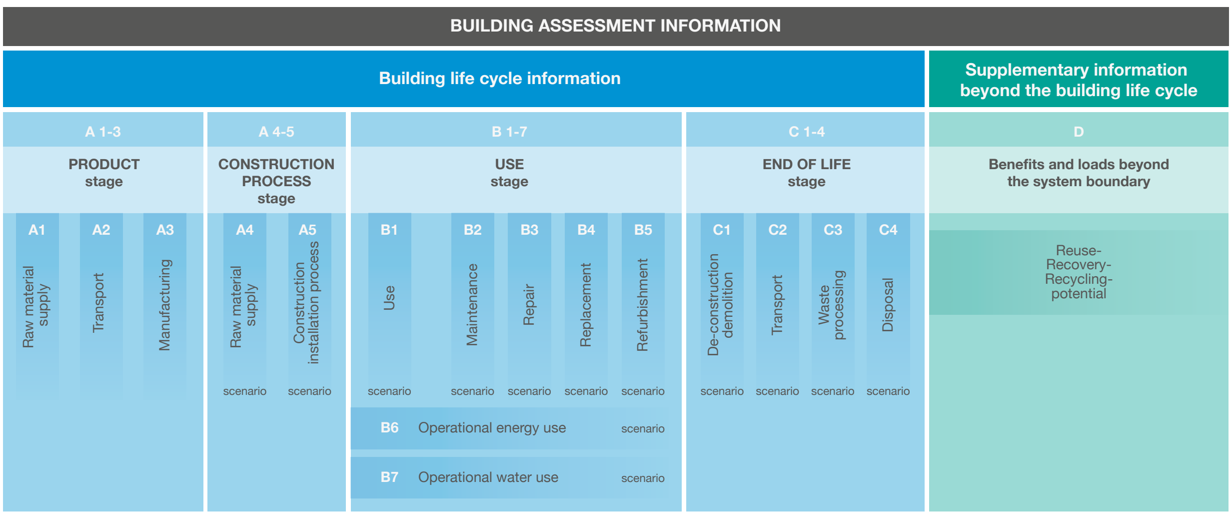


Figure 2 - BS EN 15978, Figure 6 – Life-cycle modules

To date, industry perception is that embodied carbon associated with temporary works is insignificant, where practitioners may assume it sits within the cut-off criteria, therefore not requiring calculation. In practice however, the veracity of this assumption varies greatly from project to project. For example, in refurbishment projects or heavy civils projects the majority of the embodied carbon may come from the temporary works/site activities, so disregarding temporary works may grossly underestimate the embodied carbon associated with the project. This guidance interprets the cut-off criteria to include an allowance for both the permanent and temporary works, therefore, it is incorrect to assume that all temporary works sit within the cut-off criteria. It is vital that temporary works is considered as part of a holistic approach.

1.6 Temporary works material use

The general philosophy taken by many when considering temporary works as part of an embodied carbon assessment is that material is new and will be wasted. This position is taken due to a lack of certainty over material reuse. Whilst this guidance offers only complimentary information to existing guidance, it challenges this philosophy and proposes that the reuse of temporary works materials should be considered unless there is insufficient information to consider reuse. This alternative is proposed given that if the material type and use case can be identified, then the scope for reuse should also be identifiable. This alternative approach is in an effort to promote the reuse of material and capture savings made through reuse.

It is vital that considerations for material reuse are integrated into project planning to ensure that savings made in the assessment materialise during construction. If material is not reused during construction, the calculation will be an underestimate.

1.7 Whole-life carbon assessment scope

Whilst the minimum life-cycle scope of embodied carbon assessment includes life-cycle modules A1-A5, when considering temporary works, the relatively short life-cycles provide users with greater certainty in the carbon factor data for the material EoL. As such, best practice is to consider the ‘cradle to grave’ whole-life embodied carbon (Modules A-C plus D).

It is important that those working with temporary works should do so collaboratively with other disciplines such as the Permanent Works Designer (PWD), the Client, the Principal Contractor, etc. to ensure a holistic approach to carbon reduction for the project is taken, and savings made during the design phase do not cause additional carbon spend during the construction phase. Reference is made here to the *TWf's Constructability: A guide to reducing temporary works* [9.] which emphasises the point that the PWD needs to engage early with the Temporary Works Designer (TWD) - and Contractor - to ensure a greater consideration for constructability. This holistic approach shall lead to greater carbon reductions when considering the whole life of the asset.

Where temporary works is designed to form part of the permanent works, this material can be deducted from the scope of the temporary works embodied carbon assessment.

1.8 A5 Lifecyle module

With reference to the IStructE Guide [1.], in order to add granularity to the calculation, the A5 life-cycle module associated with construction processes is split into two sub-modules:

- A5w — All emissions associated with the quantity of material that is wasted on site, i.e. the full spectrum of life-cycle modules attributed to the quantity of material wasted.
- A5a — All emissions due to general construction activities, i.e. energy use.

1.9 Temporary works as wastage

In keeping with the philosophy that “the best temporary works is no temporary works” and the concept that all material that does not form part of the final asset is waste, the embodied carbon associated with temporary works should be captured in the A5w life-cycle module. With reference to BS EN 15978 [6.], the boundary of the A5 module includes:

“temporary works, including temporary works located off-site as necessary for the construction installation process”.

Whilst considering temporary works within the A5w life-cycle module may suggest that the method referenced in this guidance is only applicable for a project level assessment, it should be noted here that the method yields the same embodied carbon value irrespective of whether an element level or project level assessment is undertaken, provided the A5a Lifecyle module is appropriately considered. Given temporary works sits within the A5 module, it is likely to represent more than 5% of energy use and mass of the life-cycle module, therefore cannot be excluded from assessment in in the ‘cut-off criteria’ in accordance with PAS 2080 [5.].

Table 2 – Life-cycle module exclusions

Life-cycle module	Justification for exclusion
B1: Use	Carbon associated with the use of temporary works is considered to be captured in the A5a life-cycle module.
B2: Maintenance	
B3: Repair	Carbon associated with the replacement/refurbishment of temporary works is considered to be captured in the A5w life-cycle module, under the waste rate.
B4: Replacement	
B5: Refurbishment	
B6: Operational energy use	Carbon associated with the use of temporary works is considered to be captured in the A5a life-cycle module.
B7: Operational water use	
C1: De-construction & Demolition	Deconstruction of temporary works is considered in module A5a as deconstruction of the temporary works is, in the majority of cases, during the lifetime of the construction project.

NOTE: Many of the Lifecycle modules described in BS EN 15978:2011 [6.] are not considered when determining a carbon factor for temporary works. Refer to Table 2 for the life-cycle modules excluded and justifications in this approach. Judgement by the Practitioner is required to ensure that that the justifications for exclusion apply to the specific project considered.

2.0 Calculation process

This chapter provides commentary on determining the embodied carbon factor (ECF) to determine the embodied carbon associated with the temporary works. It is recommended that the Practitioner refers to the IStructE's *How to calculate embodied carbon* – hereinafter referred to as the 'IStructE Guide' [1.] – (or other appropriate source) when determining ECFs for modules described.

2.1 Basic equation

The basic equation for determining the ECF associated with material wastage has been adapted from the IStructE Guide [1.]:

$$ECF_{A5w,i} =$$

$$\left(\frac{ECF_{A13,i} + ECF_{C34,i}}{N} + ECF_{A4,i} + ECF_{C2,i}\right) + \quad \text{[Component 1]}$$

$$WF_{i,tw}\,(ECF_{A13,i} + ECF_{A4,i} + ECF_{C2,i} + ECF_{C34,i}) \quad \text{[Component 2]}$$

Equation 1

where:

Component 1 = 'as designed' material quantities for temporary works elements; and

Component 2 = material wastage above the as-designed amount per use/project considered.

N = total number of times a material is reused before it reaches EoL

$$N = \begin{cases} 1 \text{ for single-use material} \\ >1 \text{ for finite reuse material} \\ >100 \text{ for high reuse/proprietary material)} \end{cases}$$

Definitions for the ECFs are taken from the IStructE Guide [1.]:

$ECF_{A5w,i}$ = construction waste embodied carbon factor for i^{th} material

$ECF_{A13,i}$ = embodied carbon factor for A1–A3 for i^{th} material

$ECF_{A4,i}$ = embodied carbon factor for transport to site for i^{th} material

$ECF_{C2,i}$ = embodied carbon factor for transport away from site for reuse for i^{th} material

NOTE: Proprietary materials may be transported back to contractor's storage/yard or any other location known at the time of calculation, e.g. straight to the next project. If this is the case, gains may be made here where their transport to a new project may be associated with the next project's A4 module and not count towards the project under consideration.

$ECF_{C34,i}$ = waste processing and disposal embodied carbon factor.

The waste factor $WF_{i,tw}$ is calculated by converting the waste rate, $WR_{i,tw}$ (a percentage of the quantity of materials brought to the site that are wasted), to the quantity of materials wasted on site as a percentage of the material quantities used in the final asset:

$$WF_{i,tw} = \left(\frac{1}{1-WR_{i,tw}} - 1\right) \quad \text{Equation 2}$$

$WR_{i,tw}$ = waste rate (quantity of materials brought to site that ends up as waste during installation and/or construction process) of ith material, which can be estimated using data in the WRAP Net Waste Tool [10.].

NOTE: To align with the IStructE Guide, the Practitioner should use the Waste Factor in Equation 1. As an alternative, this guidance proposes using the 'waste rate' ($WR_{i,tw}$) in place of the 'waste factor' ($WF_{i,tw}$) in Equation 1 and Equation 3 (refer to Appendix A).

2.2 Module D

It is recommended that module D is considered as part of a whole-life carbon assessment to account for savings made at the material EoL, where there is certainty of the recovery/recycling of the material. However, established practice is to report module D savings separately. Therefore, Equation 1 has been modified as follows:

$$ECF_{D,tw,i} =$$

$$\left(\frac{ECF_{Di}}{N}\right) \quad \text{[Component 1]}$$

$$+ WF_i\,(ECF_{Di}) \quad \text{[Component 2]}$$

Equation 3

where:

ECF_{Di} = embodied carbon factor for reuse/ recovery/recycling for the i^{th} material

2.3 Waste Rate

Practitioner judgement is required when determining an appropriate waste rate:

- Where single-use material is used, the waste rate data taken from the WRAP Net Waste Tool [10.] is likely to be appropriate, although the application to temporary works may differ.
- Where the number of uses is greater than one, the Waste Rate is equal to zero, i.e. where
  N>1, WR = WF = 0

In addition to existing published waste rates, this guidance proposes some additional material waste rates specific to temporary works applications (see Table 3). This data has been developed based on a combination of available data and experiential judgement. Practitioners may determine their own waste rates based on experience or project specific data.

2.4 Use of the IStructE Structural Carbon Tool (Version 2)

This guidance recommends the use of the IStructE *Structural Carbon Tool* (Version 2) [11.] to expedite calculations. This tool is designed with a focus on PWD and in compliance with PAS 2080 [5.]. As such, all temporary works carbon is presented in the A5 column. It is, however, understood that this makes it difficult for those considering temporary works to hotspot where the carbon lies to make meaningful reductions.

In order to make use of the IStructE *Structural Carbon Tool* (Version 2), the following inputs are recommended:

- Where temporary works are considered in isolation, by temporarily unticking the temporary works box on the main calculation sheet, the Practitioner can see the breakdown of the carbon in each module. Once the hot spotting activity is complete, materials can then be reverted back to temporary works.

  NOTE: This will not work for the maintenance line item (B) or plant emissions line item (A5a).

- In the main scheme tab, set the % of Temporary Works Wasted to 100%

Table 3 – Waste rates relating to temporary works

Material	Number of reuses, N
Below ground aluminium use	19 - 32
Above ground aluminium use	49
Below ground steel use	99
Above ground steel use	24 - 99
Plastic	9

Table 4 – Adjustments to IStructE Structural Carbon Tool (Version 2)

IStructE Structural Carbon Tool	Adjustments
Plant emissions (A5a) are inaccurately based on project value.	Set project value to £1 in project info tab. Calculate plant carbon emissions separately as described in the IStructE Guide [1.], Table C3 in Custom Data tab in the A5a cell (cell needs to be over-ridden).
Demolition plant emissions (C1) are inaccurately based on internal floor area.	Set Gross Internal Floor Area to 1m² in project info tab. Calculate plant separately as described in the IStructE Guide, Table C3 in Custom EPD C34 column and if TW, TW=100% in main calculation tab.
Excavation material is automatically added when 1.1 type is selected in the 'structural element' tab.	Set excavation removed off site to 0% to avoid this.

For each material, use the Custom Data tab:

- A1-A3 column is the A1-3 ECF divided by number of reuses, N
- A4 column is as A4 ECF
- WR column is the Net Waste WR
- C2 column is as C2 ECF
- C3-C4 column is the C3-C4 ECF divided by the number of reuses, N
- D column is as D ECF divided by the number of reuses, N

In addition, various adjustments when applying the IStructE *Structural Carbon Tool* (Version 2) to temporary works are described in Table 4.

3.0 Conclusion

The construction industry is a heavy carbon emitter. Those working in it have the responsibility and opportunity to decarbonise, this extends to the full spectrum of the industry to include those considering temporary works. The consideration for the embodied carbon associated with temporary works is still somewhat sporadic, but recent references to temporary works including in the ICE *Low Carbon Concrete Routemap* [12.] justifies that temporary works has a part to play in the route to net zero. The tools and methods described in this guidance serve no purpose other than to inform decisions to decarbonise. The quantification of embodied carbon points to the simple truth: we must use less material to progress to net zero.

The quantification of embodied carbon points to the simple truth: we must use less material to progress to net zero.

References

[1] How to calculate embodied carbon (2nd edition), IStructE (2022). Available from https://www.istructe.org/resources/guidance/how-to-calculate-embodied-carbon [Accessed: March 2023].

[2.] World Development Indicators, The World Bank (2022). Available from: https://datacatalog.worldbank.org/search/dataset/0037712 [Accessed: November 2022].

[3.] The Sixth Carbon Budget- Manufacturing and construction, Climate Change Committee (2020)

[4.] JOBS05: Workforce jobs by region and industry, The Office for National Statistics (2022)

[5.] PAS 2080: 2016, Carbon management in infrastructure. London: BSI, 2016

[6.] BS EN 15978:2011 Sustainability of construction works. Assessment of environmental performance of buildings. Calculation method. London: BSI, 2011

[7.] BS EN 15804:2012+A2:2019 Sustainability of construction works – Environmental product declarations – Core rules for the product category of construction products. London: BSI, 2012

[8.] BS 5975:2019 Code of practice for temporary works procedures and the permissible stress design of falsework. London: BSI, 2019

[9.] TWf2020:02 Constructability: A guide to reducing temporary works, The Temporary Works forum (2020)

[10.] WRAP. Net Waste Tool. Available from: https://carbon.tips/nwtool [Accessed: March 2022].

[11.] The Structural Carbon Tool Version 2, IStructE (2022)

[12.] Low Carbon Concrete Routemap, Institution of Civil Engineers (2022)

Bibliography

- Whole life carbon assessment for the built environment (1st edition), RICS (2017)
- RICS Building Carbon Database, RICS (2020)
- Embodied Carbon — The ICE Database. Circular ecology (2020). Available at: https://carbon.tips/ice3
- Bringing embodied carbon upfront, World Green Building Council (2019)

Appendix A1 - Derivation for use of 'waste rate' (WR) instead of 'waste factor' (WF) for temporary works

The purpose of the waste factor is to convert the waste rate to the quantity of materials wasted on site as a percentage of the material quantities used in the final asset.

However, as Equations 1 and 3 are split into two components, this conversion is already applied. For most situations where the Waste Rate is low (<25%), WF and WR can be used interchangeably without having a significant effect on the outcome of the calculation, but as the waste rate tends to 1, the difference between the two becomes exponential.

Consider the following example, a single-use material with an abnormally large waste rate:

Material = C40/50 (25% GGBS) insitu concrete

Material mass = 1000kg

Waste rate = 50%

Waste factor = 1

Number of reuses, N = 1

ECF_{A13} = 0.138 $kgCO_2e/kg$

ECF_{A4} = 0.005 $kgCO_2e/kg$

ECF_{C2} = 0.005 $kgCO_2e/kg$

ECF_{C34} = 0.013 $kgCO_2e/kg$

The material wasted on site is 500 kg.

Consider the material mass and the wasted material in isolation:

$$ECF_{A5w}\ [\text{Component 1}] = \left(\frac{ECF_{A13,i} + ECF_{C34,i}}{N} + ECF_{A4,i} + ECF_{C2,i}\right)$$

$$= \left(\frac{0.138\ kgCO_2e/kg + 0.013\ kgCO_2e/kg}{1} + 0.005\ kgCO_2e/kg + 0.005\ kgCO_2e/kg\right)$$

$= 0.161kg\ CO_2e/kg$

ECF_{A5w} [Component 2] = $(ECF_{A13,i} + ECF_{A4,i} + ECF_{C2,i} + ECF_{C34,i})$

= (0.138 $kgCO_2e/kg$ + 0.005 kgCO_2 e/kg + 0.005$kgCO_2e/kg$ + 0.013 $kgCO_2e/kg$)

= 0.161$kgCO_2e/kg$

Embodied carbon

= ECF_{A5w} [Component 1] × material mass

+ ECF_{A5w} [Component 2] × material wasted on site.

= 0.161$kgCO_2e/kg$ × 1000kg + 0.161$kgCO_2e/kg$ × 500kg

= 241 $kgCO_2e$

This value is considered accurate provided the ECFs used are accurate.

Appendix A1 - Derivation for use of 'waste rate' (WR) instead of 'waste factor' (WF) for temporary works – *continued*

Now consider Equation 1 using the 'waste rate':

$$ECF_{A5w,i} = \left(\frac{0.138\ kgCO_2e/kg + 0.013\ kgCO_2e/kg}{1} + 0.005\ kgCO_2e/kg + 0.005\ kgCO_2e/kg\right) +$$

$0.5 \times (0.138\ kgCO_2e/kg + 0.005kgCO_2e/kg + 0.005kgCO_2e/kg + 0.013\ kgCO_2e/kg) =$

$0.241kgCO_2e/kg$

Embodied carbon = $0.241kgCO_2e/kg \times 1000kg = 241\ kgCO_2e$

This correlates with the sum of the material considered in isolation.

Now consider Equation 1 using the 'waste factor':

$$ECF_{A5w,i} = \left(\frac{0.138\ kgCO_2e/kg + 0.013\ kgCO_2e/kg}{1} + 0.005\ kgCO_2e/kg + 0.005\ kgCO_2e/kg\right) +$$

$1 \times (0.138\ kgCO_2e/kg + 0.005kgCO_2e/kg + 0.005kgCO_2e/kg + 0.013\ kgCO_2e/kg) =$

$0.322kgCO_2e/kg$

Embodied carbon = $0.322kgCO_2e/kg \times 1000kg = 322\ kgCO_2e$

COMMENTARY

This does not correlate with the sum of the material considered in isolation. Whilst this illustrative example only evidences a difference between results at abnormally large waste rates, it demonstrates that the **waste rate** should be considered over the **waste factor** when considering the A5w life-cycle module for temporary works to prevent overestimation where the Waste Rate is greater than 25%.

A2: Derivation of Equation 1 from the IStructE Guide

Consider Equation 2.3 from the IStructE Guide [1.]:

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

If (as per section 2.2.4.1.1 of the IStructE Guide [1.]) :

$$WF_i = 1.00 + \left(\frac{\text{material}}{\text{product waste factor}}\right)$$

then:

$$ECF_{A5w,i} = \left[1.00 + \left(\frac{\text{material}}{\text{product waste factor}}\right)\right] \times (ECF_{A13,i} + ECF_{A4,i} + ECF_{C2,i} + ECF_{C34,i})$$

$$= 1.00 \times (ECF_{A13,i} + ECF_{A4,i} + ECF_{C2,i} + ECF_{C34,i}) + \left(\frac{\text{material}}{\text{product waste factor}}\right) \times (ECF_{A13,i} + ECF_{A4,i} + ECF_{C2,i} + ECF_{C34,i})$$

$$\therefore WF_{i,tw} = \left(\frac{\text{material}}{\text{product waste factor}}\right)$$

The number of reuses, N, is applied to $ECF_{A13,i}$ and $ECF_{C34,i}$ [only to Component 1] to reduce the embodied carbon pro-rata with material reuse:

$$ECF_{A5w,i} =$$

$$\left(\frac{ECF_{A13,i} + ECF_{C34,i}}{N} + ECF_{A4,i} + ECF_{C2,i}\right) + \qquad \text{[Component 1]}$$

$$WF_{i,tw}\,(ECF_{A13,i} + ECF_{A4,i} + ECF_{C2,i} + ECF_{C34,i}) \qquad \text{[Component 2]}$$

Notes:

Temporary Works forum

Chair: Rob Millard, CEng, MICE, MIDE
Secretary: David Thomas, CEng, FICE, CFIOSH, MInstRE

The Temporary Works Forum is a not for profit company (7525376) registered address (c/o Institution of Civil Engineers), 1 Great George St., London, SW1P 3AA. Correspondence address: 31, Westmorland Road, Sale, Cheshire, M33 3QX

www.twforum.org.uk
Email: secretary@twforum.org.uk