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LETI opinion piece

The Circular Economy Outcome Metric

The wider implementation of better circular economy practices in property development is hindered by the absence of consensus on a single metric for clients to use in project briefs. This Opinion Piece serves to help the convergence to such a metric, by proposing the Circular Economy Outcome Metric, a method and metric to report on the circularity credentials of property development.

Outline of the Circular Economy (CE) Outcome Metric

These first two pages serve as a concise outline of the proposed new Circular Economy (CE) Outcome Metric. The reader seeking a description of the development of the metric should skip directly to Section 1.

This proposed new CE Outcome Metric is built upon a formula for measurement that was agreed at a Hackathon of professionals (Appendix A), seeking to implement better circular economy practices in property development by simplifying the briefing process.

The CE Outcome Metric uses 'Circularity Factors' for each constituent element of a project, which are the £/kg financial costs of restitution of the environmental impact. Environmental impacts of elements are reported in Environmental Product Declarations (EPD). Each impact is weighted by a cost weighting factor W_k (different for each impact).

For each element, its material intensity (mass/m² of Gross Internal Area, GIA) is multiplied by its Circularity Factor, and then summed to give the CE Outcome Metric, in £/m². The CE Outcome Metric, and its component Circularity Factor are summarised in Equations 1 and 2 below. (More detail is in Equations 4 and 5, Section 3.0.)

$$\text{CE Outcome Metric } (\text{£}/\text{m}^2) = \sum_{\substack{\text{Sum across all}\\ \text{building elements } i}} \text{Material Intensity}_i \times \text{Circularity Factor of building element } i \text{ (financial cost of restitution of environmental impact)}$$

$$= \sum_i \frac{M_i \,(\text{kg})}{GIA \,(\text{m2})} \times F_i \,(\text{£}/\text{kg})$$

Equation 1 - The CE Outcome Metric (see Equation 5 for detail)

$$\text{Circularity Factor of building element } i \ (\text{£}/\text{kg}) = \sum_{\substack{\text{Sum across LCA modules } j \text{ and}\\ \text{Environmental Impact Factor categories } k}} \text{Environmental Impact Factor } j,k \text{ for building element } i \text{ (from EPD)} \times \text{Weighting factor to convert environmental impact } k \text{ to a financial cost of restitution of that impact}$$

$$F_i \,(\text{£}/\text{kg}) = \sum_{j,k} EIF_{ijk} \,(\text{unit}/\text{kg}) \times W_k \,(\text{£}/\text{unit})$$

Equation 2 - The Circularity Factor (see Equation 4 for detail)

The interim proposed set of cost weighting factors, W_k, are based on impact-to-€ conversion currently provided in the Dutch Environmental Performance of Buildings (Milieu Prestatie Gebouwen, or "MPG") framework. Further work is required to develop an agreed set of environmental impact weighting factors for the UK in Pounds Sterling.

Two versions of the CE Outcome Metric (Figure 1) are proposed and defined as follows:

1. **CE Outcome Metric (Whole life) identifies the total financial cost over the full life cycle of a project. It covers all EN-15804 Life Cycle Assessment (LCA) Stages A-C, with Module D reported separately. It should only be used for briefing and reporting as it contains the more subjective "future" LCA Modules.**
2. **CE Outcome Metric (Upfront) identifies the financial cost, or outcome, based on the environmental impacts of its component parts covering LCA Stage A (modules A1-A5). As these Modules are less subjective, the CE Outcome Metric (Upfront) can be used for targets, limits and performance measurement, in addition to briefing and reporting.**

This split echoes that in the proposed Part Z [1] and the UK Net Zero Carbon Buildings Standard (NZCBS). Here too, whole life embodied is carbon is intended only for reporting (and, for NZCBS, offsetting calculations), with limits only to be applied to upfront embodied carbon (and, for NZCBS, upfront energy).

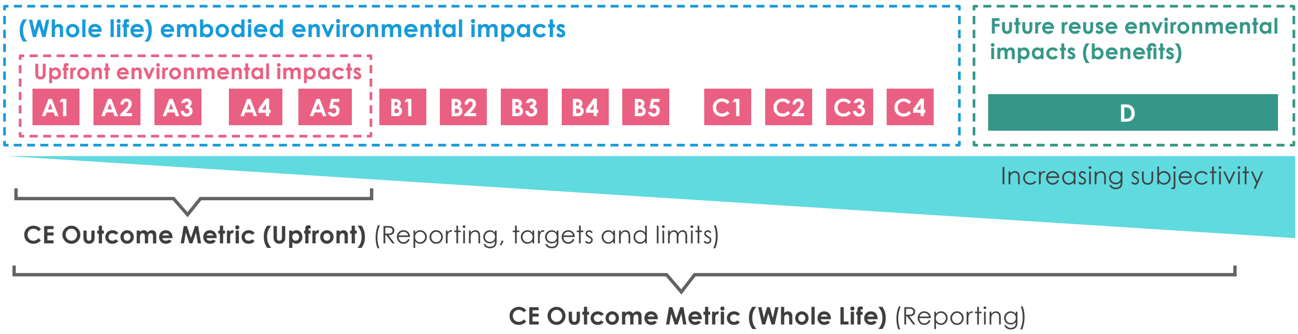

Figure 1 - CE Outcome Metric (Upfront) and CE Outcome Metric (Whole Life) mapped against LCA stages

Key Terms Used in this Opinion Piece

CE Outcome Metric: £ whole life cost of environmental externalities per m². It comes in two versions: CE Outcome Metric (Whole Life) and CE Outcome Metric (Upfront). See Equations 1 and 5.

CE Outcome Metric (Whole Life): £ whole life cost of environmental externalities per m², for use by clients for briefing and reporting of CE outcomes for building projects.

CE Outcome Metric (Upfront): £ upfront cost of environmental externalities per m², for use by clients for briefing, reporting, targets, limits, and evaluating team performance.

Hackathon Formula: Whole life, mass-weighted sum of circularity factors per m², developed at the 2023 Hackathon organised by LETI, CIRCuIT and UCL's ICEC-MCM (Equation 3).

Circularity Factor (F_i): The Circularity Factor is measured in £. It aggregates the environmental impacts from each of the categories in a material's EPD using weights that convert each impact to a £ cost of restitution of that impact.

Material Intensity (of a building element): The amount of material (kg) of a building element per m² of building area.

Client CE Outcome Criteria: Client requirements for a single metric representing CE outcomes at project completion. Developed at the 2023 Hackathon (Appendix D).

CE Design Process Criteria: Design outcome criteria. CE Process Metrics (see below) help the process of iteratively steering design actions toward these criteria, with a view to achieving more circular outcomes (Appendices B and C).

CE Process Metric: We term most (if not all) of the CE metrics already in use as CE Process Metrics as they are concerned with the design process - they steer decisions during the design and construction stages toward more circular outcomes.

Environmental Externalities: Burdens which the project places on the environment that are borne by the environment and society as a whole, not just the project client. The project doesn't incur this cost.

Contents

1.0 Background and introduction

Technical Summary

The Circular Economy Outcome Metric, or '***CE Outcome Metric***' (£/m2) is intended for use in client briefs. It is LETI's proposed method to quantify a property development's circular economy outcomes, expressed as the value of the environmental burden a project places on the planet (also known as ***Environmental Externalities***). The metric is calculated by multiplying the ***Material Intensity*** (kg/m2) by a material '***Circularity Factor***' (£/kg), aggregated for each building element (material or component) on the project.

The Circularity Factor combines the impacts from each of the categories in a building element's EPD using weights that convert each impact to a cost of restitution of that impact. The proposed set of weights are the impact-to-€ conversion values currently provided in the Dutch Environmental Performance of Buildings (MPG) framework. Existing CE metrics, most of which we define as '***CE Process Metrics***', should continue to inform the design process that drives a project's ultimate CE outcome.

Whole life and upfront impacts

There are two versions of the CE Outcome Metric. The **'CE Outcome Metric (Whole Life)'** covers all RICS LCA stages (A1-D) and should be used for briefing and reporting only, as the estimated impact of later LCA stages is more subjective. The **'CE Outcome Metric (Upfront)'** covering only Stages A1- A5 is to be used for targets, limits, and performance measurement, in addition to briefing and reporting.

The benefits of embedding circular economy principles and practice into property development include potential reduction in greenhouse gas emissions, reductions in the use of virgin resources and their associated environmental impacts, and reductions in waste. The current established strategies for good practice are multi-faceted with techniques including using less material, reuse, designing in layers, and optimising durability and replacement cycles.

One factor hindering wider implementation of better circular economy practices in property development is the absence of **consensus** on a single metric for clients to use in project briefs. This single metric must meet client criteria ('**Client CE Outcome Criteria**', see Appendix D) such as objectivity, simplicity, and ability to embed in existing processes. This Opinion Piece serves to help the **convergence** to that single consensus metric.

In January 2023, approximately 50 building industry circular economy experts met to discuss and develop consensus on the form that such a single CE metric might take. This '**Hackathon**' was organised by LETI, CIRCUiT and UCL's ICEC-MCM (Appendix A). It developed a set of client criteria to achieve CE outcomes ('**Client CE Outcome Criteria**'). It also achieved consensus on the basis of a formula for measuring the extent to which the outcome or end goal of maximising materials use circularity – minimising resource use, environmental degradation, and waste – is reached. This formula is the '**Hackathon Formula**' and is set out in Equation 3 in Section 2.0. It established that further work was required to establish the '**Circularity Factor**', F_i in the Hackathon Formula.

This Opinion piece presents the subsequent development work carried out by LETI to establish circularity factors and create the proposed **CE Outcome Metric**, which is ready to be used in practice. The Opinion Piece includes a review of existing CE metrics (Appendix B), a worked example (Section 4.0), and a review of FAQs (Appendix F).

The CE Outcome Metric also draws heavily on the detailed methodologies and parameterisation of the Dutch MPG calculation framework. MPG calculations have been mandatory in The Netherlands for over a decade now. With such a tried and tested foundation, the CE Outcome Metric can be seen as nearly ready for deployment in the UK, subject to some short-term development set out in Section 5.0.

In developing this Opinion Piece, LETI has reviewed widely used existing CE metrics. This analysis in Appendix B shows that most CE metrics are concerned with the CE design process. We have called these '**CE Process Metrics**': they help steer decisions during the design and construction stages toward more circular outcomes. Collectively they meet what we call '**CE Design Process Criteria**' (Appendices A, B and D). Unfortunately, most of these existing CE Process Metrics do not meet client criteria for a single target-setting and reporting metric. Only a handful of metrics (with the CE Outcome Metric shown as a preferred metric of choice) meet clients' requirements for a single metric showing the CE outcome at completion, to be used for benchmarking and rewarding performance.

This Opinion Piece describes the various steps and processes of evolution of the proposed metric and provides a worked example and explanation of its calculation (Section 4.0).

The CE Outcome Metric is not intended to show HOW the circularity in design and construction has been achieved (the process) but rather to represent the RESULT or outcome.

This Opinion Piece also does not seek to reject existing CE Process Metrics. These are effective and should continue to be used to inform design and construction processes, shaping the means (the design) to achieve circular outcomes.

LETI welcomes feedback to this discussion document.

2.0 The Hackathon Formula

Numerous industry bodies have proposed a wide range of different metrics for the measurement of CE features of buildings and infrastructure. Some key ones are set out and evaluated in Appendix B. Most of these are CE Process Metrics and can help steer designers to more circular designs.

Circular design and construction actions are more likely to be implemented on projects if their outcomes on projects can be part of clients' management processes, just as capital cost is, and for more progressive clients, just as whole life cost and carbon are.

The Hackathon (Appendix A) set the CE outcome criteria that real estate clients require ("**Client CE Outcome Criteria**") as:

1. Transparent, objective and robust
2. Universal and scalable
3. Simple and understandable
4. Embedded in existing processes
5. Able to evolve
6. Able to demonstrate a clear relationship with embodied carbon
7. Good for clients and society

Appendix D discusses these in more detail.

The Hackathon Formula which broadly meets the above criteria is the area standardised, mass-weighted sum of circularity factors of all products across all project life cycle stages (Equation 3).

The Hackathon Formula had considerable consensus amongst the Hackathon participants. Consensus is important as it helps:

→ reassure clients to use the metric in project briefs, in reporting, monitoring, and incentive frameworks to drive their projects to greater circularity, and

→ give confidence to regulators wishing to mandate reporting of and set minimum limits for circular materials use.

The Hackathon Formula is structured like the embodied carbon calculation, but circularity factors (F_i) are used instead of carbon factors ($kgCO_2e/kg$ of material). Like embodied carbon calculations, the final figure is summed across all materials and processes used across the development's whole life cycle. It is normalised by m^2 of floor area to allow it to be used to compare different projects.

The formula's close resemblance to embodied carbon calculations is useful because a large body of established guidance and standards already exist for the latter – such as the RICS Professional Standard on Whole life carbon assessment for the built environment, September 2023 – and it helps to identify challenges more readily and support a faster roll-out.

The Hackathon recognised that further work was necessary to develop the undefined circularity factors (F_i).

$$\text{Hackathon Formula (units undefined)} = \frac{\sum M_i \times F_i}{\text{Floor Area}}$$

Where:

- Summation is across all life cycle stages (EN 15978 modules A1-A5, B1-B5, C1-C4, D1) and all building elements
- M_i = Mass (kg)
- F_i = Circularity factor (units undefined)
- Floor area is measured in m^2

Equation 3 - The Hackathon Formula

3.0 Development of Circularity Factor and the CE Outcome Metric

The CE Outcome Metric (Equation 5) takes the Hackathon Formula (Equation 3) and does three things:

1. It details the **Circularity Factor** (F_i in the Hackathon Formula).
2. It divides the metric into two versions, the **CE Outcome Metric (Whole Life)** for briefing and reporting, and the **CE Outcome Metric (Upfront)**, for targets, limits and performance measurement, as well as briefing and reporting.
3. **Material Intensity** formalises the link between mass M_i in the Hackathon Formula's numerator and Floor Area in the denominator.

The outcome of a more circular project is a lower value of the CE Outcome Metric. This comes about through the above three items as follows:

- → Most circular design features of a project, such as a reduction of materials used, reuse and recycling of materials and components, and use of materials with a low environmental impact (see Table 7), serve to lower **Circularity Factors** and the **CE Outcome Metric (Upfront)**.
- → Furthermore, design features such as flexibility, adaptability, designing in layers, and using more durable materials alter the assumptions regarding future use (Module B1), maintenance (B2), repair (B3), replacement (B4), refurbishment (B5), deconstruction (C1), transport (C2), waste processing (C3) and disposal (C4), in many cases reducing the future impact of building element use in the **CE Outcome Metric (Whole Life)**.
- → Using a lower mass of (the same) material per unit of Floor Area lowers the **Material Intensity**.

The impact of the different circular economy approaches on the value of the CE Outcome Metric is set out in Appendix C.

The rest of this section focuses on the first two items in the above list: the Circularity Factor and the two versions of the CE Outcome Metric.

Circularity Factor, F_i

In the Hackathon Formula, the building element's mass is multiplied by the **Circularity Factor** F_i, for each building element, for each life cycle stage.

It is detailed in Equation 4, and its incorporation into the CE Outcome Metric is shown in Equation 5. An example of the calculation of F_i and the CE Outcome Metric, is in section 4.0.

In the CE Outcome Metric, the Circularity Factor is defined as the Pounds Sterling cost of restitution of the negative environmental impact per unit of mass of each building element.

A commonly used term for such negative environmental impacts is "**Environmental Externalities**". An environmental externality is a burden which the project places on the environment that is borne by the environment and society as a whole, not just the project client, the cost of which the project doesn't incur. For example, GHG emissions from the construction of a building contribute to climate change – a burden borne by the public through crop damage, excess deaths, wildfires etc, for which the building owners do not compensate the public.

EPD and restitution of Environmental Externalities

A building element's EPD is an objective representations of [2] its various environmental externalities. However, two features of EPD must be overcome before its information can be used in the Circularity Factor:

1. Most impacts in an EPD are expressed in different units, so cannot be aggregated as-is. Aggregation is only possible if each is converted to a common unit.
2. An EPD does not provide the cost of restitution of the building element's environmental impacts.

The Circularity Factor solves these two problems in one go, with the use of Environmental Impact Weighting factors, W_j. These convert each environmental impact into an economic cost to the public of making good the material's environmental burden. Also, as economic costs are all in £, they can be aggregated.

The Dutch MPG framework

The above "weighting factor" solution is borrowed from the Dutch mandatory whole life carbon reporting framework, known as MPG [3]. Reporting of MPG values for buildings has now been mandatory in The Netherlands for over a decade.

MPG uses Impact Weighting Factors to convert and combine all environmental impacts to estimate the overall cost in Euro per kg of each building element of environmental externalities of the project. These factors are set out in Appendix E.

The worked example in Section 4.0 shows the workings of this conversion calculation.

Further work is required to develop an agreed set of environmental impact weighting factors for the UK in Pounds Sterling. Consideration of how to deal with products and materials that lack EPD is also required.

Circularity Factor of building element i (£/kg)	=	$\sum$ *Sum across LCA modules j and Environmental Impact Factor categories k*	Environmental Impact Factor j,k for building element i (from EPD)	×	Weighting factor to convert environmental impact k to a financial cost of restitution of that impact

$$F_i \ (£/kg) = \sum_{j,k} EIF_{ijk}\ (unit/kg) \times W_k\ (£/unit)$$

Where:

Summation is across:

- all LCA modules **j**.

This is the only place where the difference between the two versions of the CE Outcome Metric exists:

When calculating CE Outcome Metric (Whole Life), summation is for ALL LCA modules (j = A1-A5, B1-B5, C1-C4 and D)

When calculating CE Outcome Metric (Upfront), summation is only for UPFRONT LCA modules (j = A1-A5)

- all **Environmental Impact Factor** categories (**k**, where k = ADP, GWP, ODP, POCP, AP, EP,...)

EIF_{ijk} = the building element **i**'s '**Environmental Impact Factor**' for LCA module **j** and impact category **k** (measured in various units/kg), as taken from the EPD for building element **i**.

Although mass (kg) is used as a functional unit for most building elements' EPD, some use other functional units. In those cases, it will be necessary to restate the environmental impact indicator to a rate per kg of product mass.

W_k = **Weighting Factor** to convert environmental impact **k** to a cost of restitution of that impact (£/various units).

Equation 4 - The Formula for the Circularity Factor, F_i. Only the "upfront" LCA modules are included in the calculation when determining the CE Outcome Metric (Upfront)

Two versions of the metric: CE Outcome Metric (Whole Life) and CE Outcome Metric (Upfront)

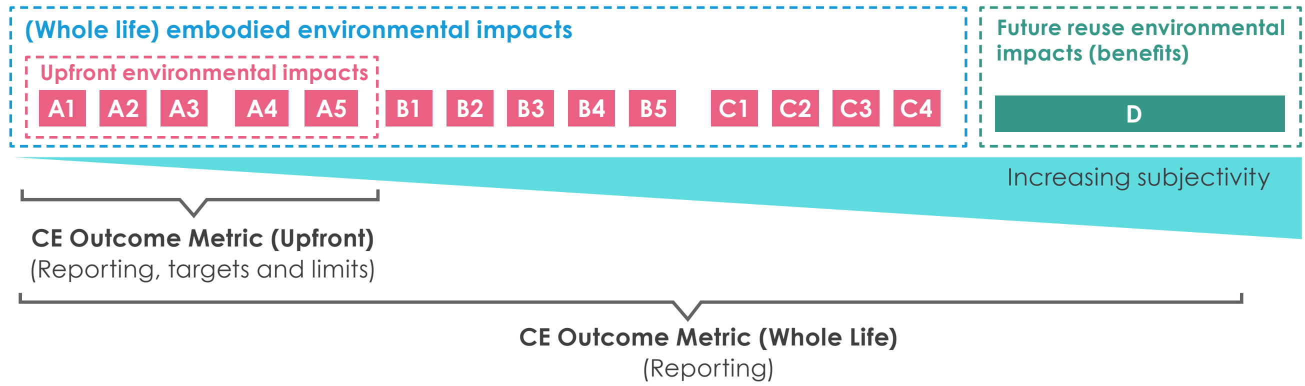

Figure 1 (repeated here from the Outline section) - CE Outcome Metric (Upfront) and CE Outcome Metric (Whole Life) mapped against LCA stages

The difference between the CE Outcome Metric (Whole Life) and CE Outcome Metric (Upfront) lies in which LCA modules are included in the calculation of the Circularity Factor (F_i) component of the CE Outcome Metric (Equation 4).

The CE Outcome Metric (Whole Life) reports on all LCA Modules (A1-5, B1-5, C1-4, D). This is the outcome of circular design, manufacturing and construction processes that extend through the project's lifetime, say, from upfront reuse to future adaptation, disassembly, and recovery.

$$\text{CE Outcome Metric } (£/m^2) = \sum_{\text{Sum across all building elements } i} \text{Material Intensity} \times \text{Circularity Factor of building element } i \text{ (financial cost of restitution of environmental impact)}$$

$$= \sum_{i} \frac{M_i \text{ (kg)}}{GIA \text{ (m2)}} \times F_i \text{ (£/kg)}$$

Where:

Summation is across all building elements (**i**)

Material Intensity = Amount of material (kg) of building element **i** per m² of building area (GIA)

= M_i (kg) / GIA (m²)

GIA = building's Gross Internal Area (GIA)

F_i = circularity factor of building element **i** (£/kg) as per Equation 4

Substituting into this the formula for F_i in Equation 4 gives:

$$\text{CE Outcome Metric } (£/m^2) = \sum_{i} \frac{M_i \text{ (kg)}}{GIA \text{ (m2)}} \times \left(\sum_{j,k} EIF_{ijk} \text{ (unit/kg)} \times W_k \text{ (£/unit)} \right)$$

Equation 5 - The CE Outcome Metric. The difference between the calculation of two versions of the metric (Whole Life and Upfront) is in the calculation of Circularity Factor F_i set out in Equation 4

The CE Outcome Metric (Upfront), however, strips out the subjective future elements and therefore meets the first client briefing criterion (objective, transparent and robust). It can therefore be used for setting targets and limits in briefs and rewarding progress to achieving circularity.

Assumptions and forecasts about future decisions and outcomes, in "future" LCA stages (B, C and D) are subjective. This makes the CE Outcome Metric (Whole Life) unsuitable for targets and limits; it should therefore only be used for reporting purposes.

This important conceptual difference between the two is set out in Figure 1 above.

Estimates and forecasts of unknown future decisions and scenarios which may or may not result in more circular materials use are still too subjective in the absence of robust standards and rules on assumptions and calculations. Long-term development of CE Outcome Metric should focus on formulating clearer rules about LCA projection assumptions – such as scope, reuse assumptions, default lifespans – that also have broad consensus.

Client familiarity

A crucial feature of the CE Outcome Metric is that it is expressed as a Pounds Sterling cost per m^2, a measurement already embedded in project management processes and recognised by clients, investors, designers, contractors, and supply chains. This can then be reported alongside more familiar financial project reporting metrics such as project capital- and whole life costs and value creation.

The CE Outcome Metric: Achieving the end-goals of a circular economy

Rather than trying to explicitly demonstrate SOME aspects of circularity (as indicators such as % reused and % reusable do), the CE Outcome Metric demonstrates the extent to which ALL "circular" design interventions have achieved reductions in environmental impacts of material choices. Appendix C contains a detailed discussion of the extent to which the CE Outcome Metric reflects the end-goals of a circular economy – ostensibly reductions in environmental impacts – as defined by the European Parliament and the Ellen McArthur Foundation.

4.0 Worked example

This worked example is for the structural frame of a 2,000m² building. The information used in the calculation has been anonymised.

The structural frame consists of only one material. Therefore "i" in Equation 5 which represents all building elements falls away in this worked example.

Step 1: Calculate the Material Intensity (kg/m²) of the structural frame material

$$\sum_{i} \frac{M_i \text{ (kg)}}{GIA \text{ (m2)}} \times \left(\sum_{j,k} EIF_{ijk} \text{ (unit/kg)} \times W_k \text{ (£/unit)} \right)$$

Within the example building, the calculated mass of structural frame material: 113,200kg = 113.2 tonne. The GIA floor area of the building is 2,000m², hence the Material Intensity of the structural frame = 56.6 kg/m² or 0.0566 tonne/m².

Step 2: Locate the EPD information for the structural frame material

$$\sum_{i} \frac{M_i \text{ (kg)}}{GIA \text{ (m2)}} \times \left(\sum_{j,k} EIF_{ijk} \text{ (unit/kg)} \times W_k \text{ (£/unit)} \right)$$

The EPD information for the structural frame material in this worked example is set out in accordance with EN 15804:2012+A2:2019, and therefore "Set 2" conversion factors in Table 12, Appendix E applies. As the EPD functional unit is 1 tonne / 1,000kg, the EPD information, set out in Table 1 below, represents 1,000 X EIF_{ijk} in Equations 4 and 5. Care is needed to check the units of for the different LCA impacts are the same as those within the "Set 2" factors in Table 12.

Impact category	Unit	A1-A3	A4, A5	C1-C4	D
Abiotic resource depletion - non fossil fuels (ADPn)	kg Sb-eq/tonne	0.00015	0.00000075	0.00135	-0.0007
Abiotic resource depletion - fossil fuels (ADPf)	MJ/tonne	11750	125	500	-2790
Global warming 100y (GWP)	kg CO2-eq/tonne	1055	9.1	50	-320
Stratospheric ozone depletion (ODP)	kg CFC-11-eq/tonne	9E-12	2E-15	0.0000035	-6E-13
Photochemical ozone formation (POCP)	kg NMVOC-eq/tonne	2.65	0.03	0.25	-0.45
Acidification potential of soil and water (AP)	mol H+-eq/tonne	3.015	0.035	0.35	-0.55
Freshwater ecotoxicity (FAETP)	CTUe/tonne	3115	92.5	1800	-4.2
Eutrophication aquatic freshwater (EPaf)	kg P-eq/tonne	0.00055	0.000009	0.00675	-0.000025
Eutrophication aquatic marine (EPam)	kg N-eq/tonne	0.855	0.015	0.087	-0.09
Eutrophication terrestrial (EPt)	mol N-eq/tonne	9.25	0.17	0.99	-0.9
Potential incidence of disease due to particle matter emissions (PM)	kg disease incidence/ tonne	0.0000375	0.00000021	0.000004	-0.00001
Potential human exposure efficiency relative to U235 (IRP)	kBq U235-eq/tonne	28	0.034	3.6	8.2
Human toxicity, cancer effects (HTP-c)	CTUh/tonne	0.00000075	0.000000002	0.00000004	0.0000001
Human toxicity, non-cancer effects (HTP-nc)	CTUh/tonne	0.000019	0.0000001	0.0000019	-0.000004

Table 1 - EPD information for 1 tonne of structural frame material. EPD often include no information for Modules B1-B5. See FAQ, Appendix E

Step 3: Locate the Environmental Impact Category weighting factors (€/unit)

$$\sum_{i} \frac{M_i \text{ (kg)}}{GIA \text{ (m2)}} \times \left(\sum_{j,k} EIF_{ijk} \text{ (unit/kg)} \times W_k \text{ (£/unit)} \right)$$

The Environmental Impact Category weighting factors set out in Table 2 below are sourced from "Set 2" in the Dutch MPG framework (Table 12, Appendix E).

Impact category	Unit	Weighting Factor (€/unit equivalent)
Abiotic resource depletion - non fossil fuels (ADPn)	kg Sb-eq	€ 0.30
Abiotic resource depletion - fossil fuels (ADPf)	MJ	€ 0.00033
Global warming 100y (GWP)	kg CO2-eq	€ 0.116
Stratospheric ozone depletion (ODP)	kg CFC-11-eq	€ 32.00
Photochemical ozone formation (POCP)	kg NMVOC-eq	€ 1.22
Acidification potential of soil and water (AP)	mol H+-eq	€ 0.39
Freshwater ecotoxicity (FAETP)	CTUe	€ 0.00013
Eutrophication aquatic freshwater (EPaf)	kg P-eq	€ 1.96
Eutrophication aquatic marine (EPam)	kg N-eq	€ 3.28
Eutrophication terrestrial (EPt)	mol N-eq	€ 0.36
Potential incidence of disease due to particle matter emissions (PM)	kg disease incidence	€ 575,838.00
Potential human exposure efficiency relative to U235 (IRP)	kBq U235-eq	€ 0.049
Human toxicity, cancer effects (HTP-c)	CTUh	€ 1,096,368.00
Human toxicity, non-cancer effects (HTP-nc)	CTUh	€ 147,588.00

Table 2 - Environmental Impact Category weighting factors ("Set 2" in Table 12, Appendix E)

Step 4: Calculate the Circularity Factors F_i (€/kg) and aggregate

$$\sum_{i} \frac{M_i \text{ (kg)}}{GIA \text{ (m2)}} \times \left(\sum_{j,k} EIF_{ijk} \text{ (unit/kg)} \times W_k \text{ (£/unit)} \right)$$

This step entails multiplying the values from steps 2 and 3, converting from the EPD declared units (tonnes) to kg, and aggregating to obtain the results set out in Table 3.

Impact category	A1-A3	A4, A5	C1-C4	D	Total A	Total A-C	Total A-D
ADPn	€ 0.0000	€ 0.0000	€ 0.0000	-€ 0.0000	€ 0.0000	€ 0.0000	€ 0.0000
ADPf	€ 0.0039	€ 0.0000	€ 0.0002	-€ 0.0009	€ 0.0039	€ 0.0041	€ 0.0032
Env Impact - GWP	**€ 0.1224**	**€ 0.0011**	**€ 0.0058**	**-€ 0.0371**	**€ 0.1234**	**€ 0.1292**	**€ 0.0921**
ODP	€ 0.0000	€ 0.0000	€ 0.0000	-€ 0.0000	€ 0.0000	€ 0.0000	€ 0.0000
POCP	€ 0.0032	€ 0.0000	€ 0.0003	-€ 0.0005	€ 0.0033	€ 0.0036	€ 0.0030
AP	€ 0.0012	€ 0.0000	€ 0.0001	-€ 0.0002	€ 0.0012	€ 0.0013	€ 0.0011
FAETP	€ 0.0004	€ 0.0000	€ 0.0002	-€ 0.0000	€ 0.0004	€ 0.0007	€ 0.0007
EPaf	€ 0.0000	€ 0.0000	€ 0.0000	-€ 0.0000	€ 0.0000	€ 0.0000	€ 0.0000
EPam	€ 0.0028	€ 0.0000	€ 0.0003	-€ 0.0003	€ 0.0029	€ 0.0031	€ 0.0028
EPt	€ 0.0033	€ 0.0001	€ 0.0004	-€ 0.0003	€ 0.0034	€ 0.0037	€ 0.0034
PM	€ 0.0216	€ 0.0001	€ 0.0023	-€ 0.0058	€ 0.0217	€ 0.0240	€ 0.0183
IRP	€ 0.0014	€ 0.0000	€ 0.0002	€ 0.0004	€ 0.0014	€ 0.0016	€ 0.0020
HTP-c	€ 0.0008	€ 0.0000	€ 0.0000	€ 0.0001	€ 0.0008	€ 0.0009	€ 0.0010
HTP-nc	€ 0.0028	€ 0.0000	€ 0.0003	-€ 0.0006	€ 0.0028	€ 0.0031	€ 0.0025
Env Impact - Excl GWP	**€ 0.0414**	**€ 0.0004**	**€ 0.0043**	**-€ 0.0081**	**€ 0.0418**	**€ 0.0461**	**€ 0.0379**
Env Impact - Total	**€ 0.1638**	**€ 0.0014**	**€ 0.0101**	**-€ 0.0453**	**€ 0.1652**	**€ 0.1753**	**€ 0.1300**

Table 3 - Calculated Circularity Factors for the structure of the example building

Step 5: Multiply by Material Intensity to calculate the CE Outcome Metric (€ /m²) for the structural frame

This step entails multiplying the values from steps 1 and 4 to obtain the results set out in Table 4.

$$\sum_{i} \frac{M_i \text{ (kg)}}{GIA \text{ (m2)}} \times \left(\sum_{j,k} EIF_{ijk} \text{ (unit/kg)} \times W_k \text{ (£/unit)} \right)$$

Impact category	A1-A3	A4, A5	C1-C4	D	Total A	Total A-C	Total A-D
ADPn	€ 0.00	€ 0.00	€ 0.00	-€ 0.00	€ 0.00	€ 0.00	€ 0.00
ADPf	€ 0.22	€ 0.00	€ 0.01	-€ 0.05	€ 0.22	€ 0.23	€ 0.18
Env Impact - GWP	**€ 6.93**	**€ 0.06**	**€ 0.33**	**-€ 2.10**	**€ 6.99**	**€ 7.31**	**€ 5.21**
ODP	€ 0.00	€ 0.00	€ 0.00	-€ 0.00	€ 0.00	€ 0.00	€ 0.00
POCP	€ 0.18	€ 0.00	€ 0.02	-€ 0.03	€ 0.19	€ 0.20	€ 0.17
AP	€ 0.07	€ 0.00	€ 0.01	-€ 0.01	€ 0.07	€ 0.08	€ 0.06
FAETP	€ 0.02	€ 0.00	€ 0.01	-€ 0.00	€ 0.02	€ 0.04	€ 0.04
EPaf	€ 0.00	€ 0.00	€ 0.00	-€ 0.00	€ 0.00	€ 0.00	€ 0.00
EPam	€ 0.16	€ 0.00	€ 0.02	-€ 0.02	€ 0.16	€ 0.18	€ 0.16
EPt	€ 0.19	€ 0.00	€ 0.02	-€ 0.02	€ 0.19	€ 0.21	€ 0.19
PM	€ 1.22	€ 0.01	€ 0.13	-€ 0.33	€ 1.23	€ 1.36	€ 1.03
IRP	€ 0.08	€ 0.00	€ 0.01	€ 0.02	€ 0.08	€ 0.09	€ 0.11
HTP-c	€ 0.05	€ 0.00	€ 0.00	€ 0.01	€ 0.05	€ 0.05	€ 0.06
HTP-nc	€ 0.16	€ 0.00	€ 0.02	-€ 0.03	€ 0.16	€ 0.18	€ 0.14
Env Impact - Excl GWP	**€ 2.34**	**€ 0.02**	**€ 0.24**	**-€ 0.46**	**€ 2.36**	**€ 2.61**	**€ 2.15**
Env Impact - Total	**€ 9.27**	**€ 0.08**	**€ 0.57**	**-€ 2.56**	**€ 9.35**	**€ 9.92**	**€ 7.36**

Table 4 - Calculated CE Outcome Metric - detail

From this detailed table of values, the required version of the CE Outcome Metric can be selected. In addition, it is possible to select whether or not to incorporate the impact of GWP and/or Module D. See Table 5 below.

The CE Outcome Metric (Whole Life) for the structural frame is €9.92/m², reducing to €7.36/m² when incorporating the benefit from Module D. The CE Outcome Metric (Upfront) is €9.35/m².

The GWP weighting factors determine the ratio of the GWP (carbon) environmental impact to the total, which is 75% for the CE Outcome Metric (Upfront) and 71%-75% for the CE Outcome Metric (Whole Life)

It is interesting to note that the approximate capital cost of the structural frame is estimated to be in the region of 10-15 times the total environmental externalities cost calculated as per the CE Outcome Metric methodology. This ratio is very sensitive to the values of the Environmental Impact Category weighting factors in Step 3.

Impact category	CE Outcome Metric (Upfront) (Stage A)	CE Outcome Metric (Whole Life) (Stages A-C)	CE Outcome Metric (Whole Life) Incorporating benefit from Module D
Environmental Impact - GWP	€ 6.99/m² (75%)	€ 7.31/m² (74%)	€ 5.21/m² (71%)
Environmental Impact - Excluding GWP	€ 2.36/m² (25%)	€ 2.61/m² (26%)	€ 2.15/m² (29%)
Environmental Impact - Total	**€ 9.35/m² (100%)**	**€ 9.92/m² (100%)**	**€ 7.36/m² (100%)**

Table 5 - Calculated CE Outcome Metric - summary

5.0 Next steps for further development

Short-term development

A proof-of-concept testing exercise to calculate the CE Outcome Metric on several live projects will help identify strengths and weaknesses and help prioritise areas for further development.

An agreed set of environmental impact weighting factors (representing the cost of externalities) needs to be developed. A starting point might be the weighting factors set out in the Dutch MPG calculation (Appendix E). More generally, further work is needed to understand how to convert relevant elements of the Dutch MPG framework to the CE Outcome Metric.

The extent of products for which EPD are available remains limited. The Dutch MPG framework deals with this problem by having a "Category 3" database of default generic environmental impact factors to substitute into the calculations, not unlike the ICE database for carbon (GWP) [4]. To encourage projects to source products with EPD, the Category 3 database sets impact factors approximately 30% higher than the independently tested factors in Categories 1 and 2. A similar free database of environmental impact factors should be developed for the UK, starting off at fairly low granularity.

The lack of EPD is particularly pronounced (and is likely to remain so) for products with high reused content. Suitable workarounds will need to be developed, starting off with general adjustment factors. A free database containing standard tables of default environmental impact adjustment factors for different product reuse levels should be developed to bridge the lack of EPD [5].

In parallel to the above, efforts to maintain and expand the consensus gained at the Hackathon needs to continue. Consensus-building might take the form of formal working groups, seminars, projects carrying out and interrogating the calculations of the CE Outcome Metric and other CE metrics for live building developments, dialogue with experts in the Dutch MPG framework, and so on.

Longer-term development

Estimates and forecasts of unknown future decisions and scenarios are still too subjective in the absence of robust standards and rules on assumptions and calculations. Whilst this remains the case, clients will favour the CE Outcome Metric (Upfront) to evaluate project performance. Long-term development of CE Outcome Metric should focus on formulating clearer rules about LCA projection assumptions – such as scope, reuse assumptions, default lifespans – that also have broad consensus, so that the CE Outcome Metric (Whole Life) can also be used for setting limits and evaluating and rewarding performance.

Furthermore, work on developing the free database of environmental impact factors should continue to increase granularity of detail to better differentiate between products.

Finally, consideration should be given to extending the impact categories beyond those set out in the EPD, such as social value and biodiversity net gain, once consensus on objective means of measuring these has been reached.

Appendix A: Details of the Hackathon

On 12 January 2023 a Hackathon organised by LETI, CIRCuIT and UCL took place in Central London. It was organised to form consensus on a single usable and effective CE metric to assess circularity in buildings, which clients can use to set CE briefs.

A literature review by UCL prior to the event identified 100+ different indicators, metrics and approaches to demonstrate material circularity. Further research would no doubt unearth many more. This bewildering landscape of divergence was found to stand in contrast to the consensus on whole life carbon as the single metric representing carbon emissions over a building's life.

The key concern that the Hackathon sought to address was the ongoing lack of consensus on such a metric for circularity. This lack of consensus prevents real estate industry clients from developing a circular economy brief on projects; many consider this to be a key blocker to greater circularity in building projects.

The day-long workshop brought together approximately 50 building industry circular economy experts to work in groups, each addressing a different stage of the building's life cycle: construction; in-use; and end of life.

The day's first task was to review pre-recorded interviews with representatives from five clients: British Land; London Borough of Camden; Landsec; Meridian Water; and London & Quadrant Housing Trust. The clients set out their criteria for metrics generally, and for CE metrics.

Circular design and construction actions are more likely to be implemented on projects if their outcomes on projects can be part of clients' management processes just as capital cost is, and for more progressive clients, just as whole life cost and carbon are.

The distilled criteria show that clients prioritise a measure of overall CE outcomes to use in briefs, not measures that reflect the design process. Table 6 sets out these CE outcome criteria "Client CE Outcome Criteria"). These criteria represented the brief for the day's work to develop the single circularity metric.

Client CE Outcome Criteria
1. Objective, transparent and robust
2. Universal and scalable
3. Simple and understandable
4. Embedded in existing processes
5. Able to evolve
6. Able to demonstrate a clear relationship with embodied carbon
7. Good for clients and society

Table 6 - Client CE Outcome Criteria

Typical circular Economy Design Process Criteria
1. Use less/optimise design
2. Reuse structures, components, and materials
3. Use recycled content or secondary materials
4. Share materials for onward use
5. Use low impact materials
6. Design in layers
7. Use more durable materials and components
8. Flexible design
9. Adaptable design
10. Design for disassembly and recoverability
11. Design out waste

Table 7 - Typical CE Design Process Criteria

The Hackathon consciously did not set out to list the already well-established design criteria for achieving CE. A set of typical criteria for the CE design process, derived from the UKGBC document "Circular economy guidance for construction clients" [6] is set out in Table 7. This Opinion Piece refers to these as CE Design Process Criteria.

Both the Client CE Outcome Criteria and CE Design Process Criteria are used to evaluate all metrics discussed in this Opinion Piece, in Appendix B.

The above-named client representatives joined the proceedings at the end of the day in a 'Dragon's Den'-style evaluation of the groups' work. The overwhelming consensus fell on a metric (The

Hackathon Formula – Equation 3) that in its simplest form is a conceptual parallel to whole life carbon, using circularity factors instead of carbon factors. As such the Hackathon's goal of rapid convergence and developing a metric that clients could use to set briefs – and that could eventually form the basis of regulations – had been achieved.

Hackathon organisers:

- LETI: Tim den Dekker – Feilden Clegg Bradley Studios, Mirko Farnetani – SOM
- CIRCuIT: Andrea Charlson – ReLondon, Tessa Devreese – ReLondon
- UCL's ICEC-MCM: Lisa Hanselmann – UCL
- Ben Cartwright (now at Reusefully)

Hackathon facilitator: Josie King

Hackathon client contributors:

- Alexia Laird – Landsec
- Giorgia Franco – London & Quadrant Housing Trust
- Matt Webster – British Land
- Nicola Tulley – London Borough of Camden
- Rafe Bertram – Enfield Council

Hackathon circular economy expert participants:

- Aiduan Borrion – UCL
- Alejandra Pavon-Iberri – Greengage Environmental
- Andrew Vivian – Loughborough University
- Angeliki Kourmouli – Lancaster Environment Centre
- Anna Surgenor – Arup
- Asif Din – Perkins&Will
- Boral Soumava – University of Leeds
- Bruno Fernandes – University of Leeds
- Cinthia Espino – Foster + Partners
- Danielle Densley Tingley – University of Sheffield
- Dave Cheshire – AECOM
- Elaine Toogood – The Concrete Centre/MPA
- Evangelia Manola – UCL
- Feja Lesniewska – UCL
- Flavie Lowres – BRE
- Gianluca Rapone – FDMC
- Hannah Kissick – CPW
- Harry Partridge
- Hayley Cormick – Useful Projects
- Irene Josa – UCL
- Johanna Moro – ACAN
- Julia Stegemann – UCL
- Kat Scott – dRMM
- Kell Jones – UCL
- Kim Gault – Cundall
- Kirsty Sutherland – Expedition Engineering
- Laura Batty – Heyne Tillett Steel/LETI
- Longxiang Zhao – Loughborough University
- Lynne Burden – MACE
- Maya Fookes – BEIS
- Michael Sansom – BCSA
- Nicholas Pigula – Unite
- Oli Haddon – Foster + Partners
- Rachel Hoolahan – Orms
- Ramya Venkataraman – Sustainable Merton
- Ruth Marsh – Sheppard Robson
- Saskia Manson – Eckersley O'Callaghan
- Sophia Ceneda – Glenn Howells Architects Ltd
- Sophie Collier – Elliott Wood
- Suzana Grubnic – Loughborough University
- Tom Rogerson – ISG
- Yara Machnouk – Elementa Consulting
- Yiping Meng – Loughborough University

The Hackathon organisers arranged a follow-up roundtable on 7 March 2023 to continue the discussions.

The Hackathon follow-up roundtable was attended by:

- Anna Surgenor – Arup
- Asif Din – Perkins&Will
- Ben Cartwright – Reusefully
- Danielle Densley Tingley – University of Sheffield
- Dave Cheshire – AECOM
- Flavie Lowres – BRE
- Giorgia Franco – London & Quadrant Housing Trust
- Hayley Cormick – Useful Projects
- Kat Scott – dRMM
- Katherine Adams – Reusefully
- Matt Webster – British Land
- Mirko Farnetani – SOM
- Nicola Tulley – London Borough of Camden
- Oli Haddon – Foster + Partners
- Rachel Hoolahan – Orms
- Rafe Bertram – Enfield Council
- Sophie Collier – Elliott Wood
- Tessa Devreese – CIRCuIT, ReLondon
- Tim den Dekker – Feilden Clegg Bradley Studios

Any of the information and views expressed anywhere in this Appendix and rest of the Opinion Piece do not necessarily represent the views and opinions of the Hackathon and subsequent round table organisers, client contributors and participants, and the organisations to which they have affiliations.

Appendix B: Assessment and comparison of existing CE metrics

In this appendix, the CE Outcome Metric is compared with other key CE metrics.

Reference frameworks

The following frameworks were used as sources of a reference set of CE metrics:

1. EU Level(s) [7];
2. UKGBC [8];
3. The Netherlands' "The New Normal" [9]; and
4. The two LETI metrics set out in the 2020 Embodied Carbon Primer [10].

The metrics in these frameworks are listed in Table 8 below.

Most of these existing metrics are CE Process Metrics which help steer decisions during the design and construction stages toward more circular outcomes. The metrics are therefore grouped by CE design theme. [*] This grouping, rather than grouping by the typical CE Design Process Criteria in Table 7, was done for legibility.

Of the metrics, only MPG, listed in the framework "The New Normal" (TNN1.1), is part of a regulated reporting and limits system, in this case, The Netherlands.

CE design theme [*]	EU Levels metrics group	UKGBC metrics group	"The New Normal" metrics group (Netherlands)	LETI Embodied Carbon Primer 2020 metrics
Reduce upfront mass (1)	EU Levels 2.1(a): Upfront mass/m^2	UKGBC 1: Upfront Mass/ m^2		
Reduce lifetime mass (1)	EU Levels 2.1(b): Lifetime mass/m^2	UKGBC 2: Lifetime Mass/ m^2		
Reduce construction and demolition waste (6, 7, 10, 11)	EU Levels 2.2(a): Demolition and construction waste mass/m^2 EU Levels 2.2(b): Demolition and construction waste cost of landfill		TNN1.8: % demolition reuse, mass-weighted TNN1.9: % construction waste reuse, mass-weighted	
Maximise adaptability (6, 8, 9)	EU Levels 2.3: Mass-weighted adaptability score	UKGBC 6: % of building area designed for adaptability	TNN1.6: % adaptability score, mass-weighted	
Design for disassembly/ reuse (6, 10)	EU Levels 2.4(a): Mass-weighted [and 2.4(b): value-weighted] circularity score (design for deconstruction and reuse)	UKGBC 3: % of mass designed for disassembly	TNN1.5: % reuse potential, mass-weighted TNN1.7: % composite disassembly index	LETI 2020(1): % reusable
Specify materials that are reused, remanufactured, or recycled (2, 3, 4)		UKGBC 4: Mass-weighted reuse/ remanufacture/ recycling score	TNN1.4: % renewable, reused, recycled by mass	LETI 2020(2): % reused
Reduce toxicity (5)			TNN1.10: Number of products certified non-toxic	
Use materials passports (10)		UKGBC 5: % by mass of materials with materials passports		
Reduce embodied carbon (1, 5)		UKGBC 7: (whole life) embodied carbon/m^2	TNN1.2: upfront embodied carbon/m^2 TNN1.3: sequestered CO_2/m^2	
Reduce lifetime externalities (5)			TNN1.1: MPG = Whole life materials externalities cost/m^2/lifetime (years)	

Table 8 - Existing CE metrics. The numbers in brackets for each design theme refer to the typical CE Design Process Criteria in Table 7

The GLA Circular Economy Statement

The Circular Economy Statement which London's GLA requires large schemes to submit is not a metric [11]. Rather, it is in essence a template containing a series of input sheets that collates qualitative design information and quantitative project data that could be combined to calculate some of the existing CE metrics set out here.

Evaluating the metrics

A rudimentary evaluation of the suitability of the CE Outcome Metric (Whole Life, and Upfront) and existing CE metrics is given in Table 9 further down in this Section.

The evaluation is split into suitability as a CE outcome metric and suitability as a CE design metric. Note that any "whole life" metrics or metrics predicting future events are marked down for the subjectivities embedded in the many assumptions needed for their calculation.

The evaluation is rudimentary because it is difficult to objectively 'score' the metrics for each criterion and combine the scores. A simple arithmetic total score is given for each section (CE outcome and CE design).

The disadvantages from a client briefing / CE outcome perspective of low scoring metrics are summarised as:

1. Many metrics are subjective, based on interpretive scoring systems or requiring assumptions about the future. Although these metrics are useful for helping shape the complex array of decisions typical of the design process, the operator bias contained within makes them unattractive for briefing, benchmarking, performance measurement, and eventually legislation. Clients (and eventually regulators) need confidence in a metric for which they will enforce limits; it must therefore be based on objective inputs.
2. Some metrics (such as percentages) are unitless which precludes scaling by simple aggregation across materials in a project, and across projects. Typically, mass is used to weight the numerator and denominator, but this leads to distortions as a material's mass alone is not a consistent or reliable indicator of environmental impact. To aggregate such unitless metrics, the variables to be used for weighting (e.g., mass, or the environmental impact itself which is part of the CE Outcome Metric) need to be reported in parallel.
3. Unitless metrics don't indicate absolute impact and therefore cannot be incorporated into entity or national budgets (as is, e.g., currently done with GWP for NDCs).
4. The many existing CE metrics are without hierarchy or ranking indicating priority for specific purposes (which in the case of this Opinion Piece is client briefing or measuring CE outcomes, and for which the CE Outcome Metric is intended).

In Table 9, The metrics scoring the highest on the Client CE Outcome Criteria are, in decreasing order:

1. CE Outcome Metric (Upfront), tied with TNN 1.2 (upfront embodied carbon).
2. CE Outcome Metric (Whole Life), tied with TNN 1.1 (MPG).
3. UKGBC 7 (embodied carbon).

In Table 9, metrics scoring the highest in the typical CE Design Process Criteria are, in decreasing order:

1. CE Outcome Metric (Whole Life), tied with UKGBC 7 (embodied carbon).
2. TNN 1.1 (MPG).
3. CE Outcome Metric (Upfront), tied with

   EU Levels 2.4 (a) and (b)

   UKGBC 3

   TNN 1.2 (Upfront embodied carbon)

   TNN 1.5

   TNN 1.7.

Organisational diagram of all CE metrics

Figure 2 presents one way of organising all CE metrics according to degree of objectivity (linked to Client CE Outcome Criterion 1: Objective, transparent and robust) and extent of reflecting environmental externalities (linked to Client CE Outcome Criterion 7, Good for clients and society). Also included are the following related management reporting metrics:

- → Whole life embodied carbon cost (£/m^2) calculated using prevailing carbon prices
- → Upfront embodied carbon cost (£/m^2) calculated using prevailing carbon prices
- → Whole life cost (£/m^2)
- → Capital (upfront) cost (£/m^2)

The metrics themselves are arranged in the middle box. Lines connect them to their constituent indicators, with the objective indicators on the left and subjective on the right. The greater the extent of environmental externalities, the higher up in the table they are. The CE Outcome Metric are shown in red text.

The metrics towards the top left meet Client CE Outcome Criteria 1 and 7. They are more objective and more representative of environmental externalities, and appear the most suitable for client briefing, reporting, targets, limits, performance measurement and benchmarking, and evaluating CE outcomes. The metrics towards the top right are also most representative of environmental externalities, but should only be used for reporting CE outcomes and not, due to their subjective nature, for setting limits and evaluating and rewarding performance achieving CE outcomes. Most metrics shown qualify as CE Process Metrics, as they are appropriate for evaluating and steering the CE design process.

Simple scoring of circular economy metrics

Criteria	EU Levels 2.1(a) and (b)	EU Levels 2.2(a) and (b)	EU Levels 2.3	EU Levels 2.4 (a) and (b)	UKBBC 1	UKBBC 2	UKBBC 3	UKBBC 4	UKBBC 5	UKBBC 6	UKGBC 7 (Embodied carbon)	TNN1.1 (MPG)	TNN1.2 (Upfront EC)	TNN1.3	TNN1.4	TNN1.5	TNN1.6	TNN1.7	TNN1.8	TNN1.9	TNN1.10	LETI 2020(1)	LETI 2020(2)	CE Outcome Metric (Whole Life)	CE Outcome Metric (Upfront)
Client CE Outcome Criteria																									
1. Objective, transparent and robust	●											○	●											○	●
2. Universal and scalable	●				●	●					●	●	●											●	●
3. Simple and understandable	●	●			●	●					●	●	●											●	●
4. Embedded in existing processes	●				●	●					●	●	●											●	●
5. Able to evolve											●	●	●											●	●
6. Clear relationship with embodied carbon											●	●	●	●										●	●
7. Good for clients and society											○	○	○											○	○
Simple score/7	4.0	1.0	0.0	0.0	4.0	4.0	0.0	0.0	0.0	0.0	5.5	6.0	6.5	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.0	6.5
Typical CE Design Process Criteria																									
1. Use less/optimise design	●	○			●	●	○	●			●	●	●		●	○		○	●				●	●	●
2. Reuse structures, components, and materials			○				○	●	●	○	●	●	●		●	○		○	●				●	●	●
3. Use recycled content or secondary materials								●			●	●	●		●				●				●	●	●
4. Share materials for onward use				●			●		●							●		●				●		○	
5. Use low impact materials			○								●	●	●	●							●			●	●
6. Design in layers				●			○			○	○	○				○		●				●		○	
7. Use more durable materials and components											●	○										●		●	
8. Flexible design			○	●			○			○	○	○				○		○						○	
9. Adaptable design			●	●			○			●	○	○				○	●	○						○	
10. Design for disassembly and recoverability			○	●			●		●	○	○	○				●		●				○		○	
11. Design out waste		●	○	○			○	●		○	●	●	●		●	●		○	●	●		○	●	●	●
Simple score/11	1.0	1.5	3.5	5.0	1.0	1.0	5.0	4.0	4.0	3.5	8.5	8.0	5.0	1.0	4.0	5.0	1.0	5.0	4.0	1.0	1.0	3.0	4.0	8.5	5.0

Table 9 - Simple scoring of key CE metrics from Table 8, together with CE Outcome Metric (Whole Life) and CE Outcome Metric (Upfront) in the last two columns

● Fully complies
○ Partially complies
Scores at or above 5 out of 7 on Client CE Outcome Criteria
Metric scores at or above 5 out of 11 on CE Design Process Criteria

Organisational diagram of circular economy metrics

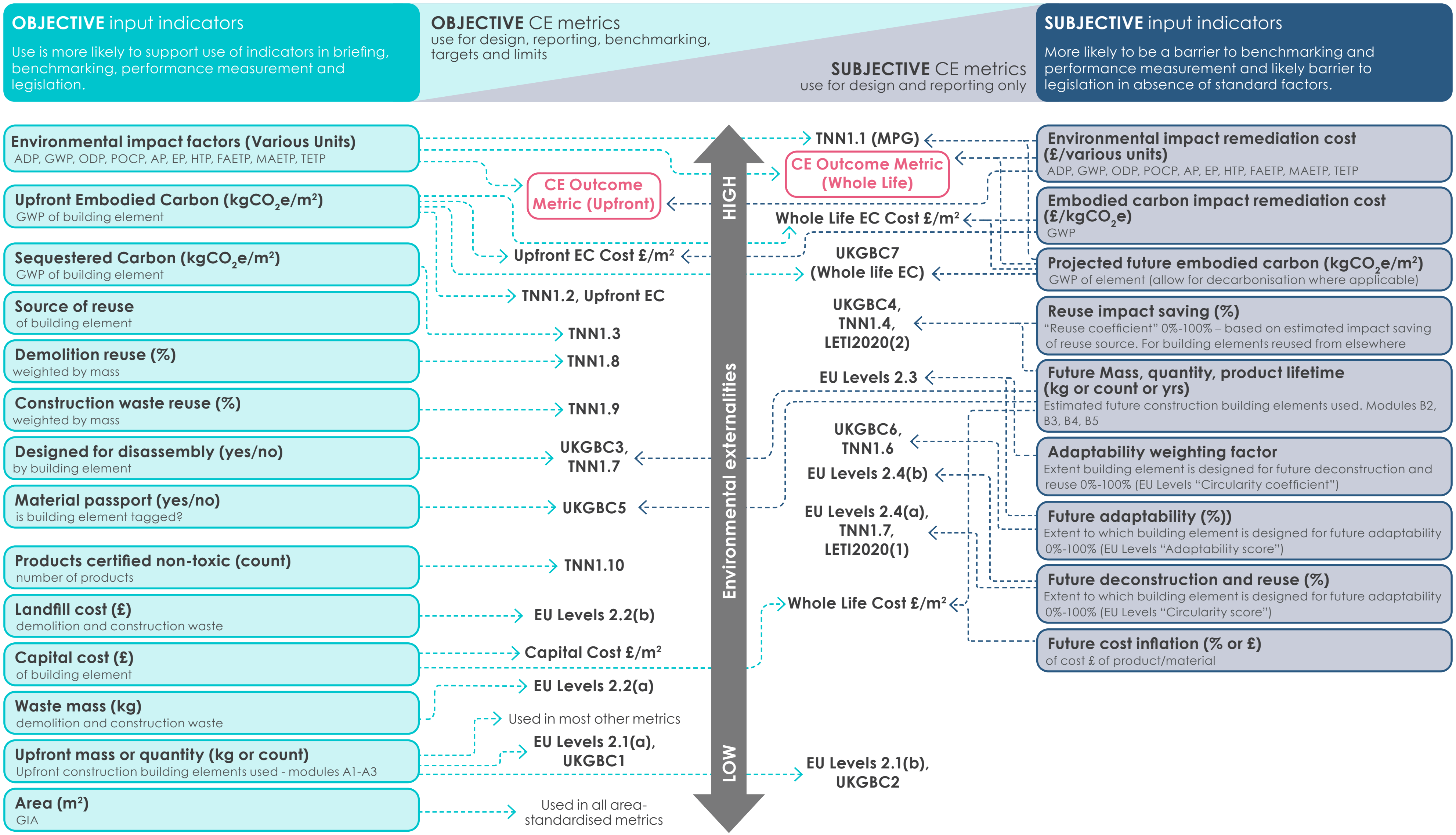

Figure 2 - Organisational diagram of all CE metrics (from Table 8), together with other key management metrics. The CE Outcome Metric (Whole Life) and CE Outcome Metric (Upfront) are shown in pink boxes

Appendix C: How the CE Outcome Metric measures up against the end-goals of a circular economy

The CE outcomes being measured: the end-goals of a circular economy approach

The CE Outcome Metric needs to do what's written on the box: measure the outcomes or end goals of CE in construction. The CE Design Process Criteria in Appendix A Table 7 set out the means – or processes or ways of achieving – CE in construction, but they don't succinctly define the outcome or end goal of a circular economy in construction.

Using definitions by the European Parliament and the Ellen McArthur Foundation, the end goals of CE can be defined as follows [12]:

1. To minimise resource use (overall, primary and scarce resources);
2. To minimise contribution to environmental degradation of extraction, manufacturing, and distribution (even that of reusing and recycling); and
3. To minimise waste.

All of these end goals are aligned with minimising externalities.

How is "minimising resource use" taken into account?

First, looking at minimising **overall** resource use:

→ This will be reflected in the Hackathon Formula through minimising M_i. The mass of materials used reflects overall resource use, which is represented by the M_i in the formula. The CE Outcome Metric normalises mass by area to restate this as Material Intensity.

→ Mi and Material Intensity used on their own cannot distinguish between primary resources and reused materials, between plentiful and scarce resources, between materials with different environmental impacts, and between projects that do and don't generate a lot of waste – this role must be handled by F_i, the Circularity Factor. See below.

Secondly, looking at minimising **primary** resource use:

→ This will be reflected in the Hackathon Formula through minimising F_i.

→ The CE Outcome Metric develops F_i – the aim being for it to be minimised – as follows:

→ The values of F_i for two similar products containing different proportions of primary vs. reused materials should reflect those different proportions. For example, in simple terms, the F_i for the same product but 50% directly reused non-primary components should be around 50% of that for one made of purely primary materials, assuming that reuse/recycling processes have significantly lower environmental impact.

→ Environmental impact per unit of mass seems to be a reasonable weighting additional to mass: As Fi is weighted by Material Intensity (Mass Mi/ Area), it is reasonable that materials with a greater environmental impact by mass should have a greater Fi (as an indicator of primary resource use) per unit of mass and receive a greater absolute reduction in Fi per unit of mass from reuse. For example, the mass-weighted impact of reusing aggregate (say, in concrete) should be much smaller than the mass-weighted impact of reusing steel or aluminium.

→ The most objective, formally verified, information of a product's environmental impact is its EPD. Therefore F_i as an indicator of primary resource use should be based on information derived from EPD. It is worth noting that whole life carbon uses GWP as the environmental impact weighting. Substituting GWP for F_i in the Hackathon Formula yields the formula for whole life carbon.

→ Minimising F_i defined in this way will prioritise resource reuse over primary resource use.

Finally, looking at minimising **scarce** resource use:

- → This will be reflected in the Hackathon Formula through minimising F_i.
- → The CE Outcome Metric develops F_i further, as follows: Scarcity of the resources used in a product – besides being reflected in the £ cost of the product – is represented by the EN-15804 environmental impact indicator abiotic depletion potential (ADP), as reported in a product's EPD. ADP is therefore an objective proxy for F_i as an indicator of resource scarcity.

How is "minimising contribution to environmental degradation" taken into account?

This will be reflected in the Hackathon Formula through minimising F_i.

For the CE Outcome Metric, as already discussed, the most objective, formally verified, information of a product's environmental impact is its EPD, and therefore F_i as an indicator of environmental impact should be derived from information derived from EPD. EPD are available for a rapidly growing set of materials and products on publicly available global databases. A short discussion about what to do if EPD are not available is given in the main text and Appendix G (FAQs).

How is "minimising waste" taken into account?

First, looking at minimising waste during the design and construction stages:

- → This will be reflected in the Hackathon Formula through minimising F_i.
- → The CE Outcome Metric develops F_i – the aim being for it to be minimised – as follows:
  - → Minimising waste during the design and construction stages – which involves reusing more, sending more of the site's existing asset for reuse, and avoiding landfill – is aligned with minimising resource use, with F_i defined in "minimising primary resource use" above.
  - → Similarly, reusing more from elsewhere is reflected in a lower F_i as defined in "minimising primary resource use" above.
  - → Reusing more by sending more of the site's existing asset for reuse (e.g., by disassembly of existing building to be replaced) should be reflected in Module D1. Increasing Module D1 lowers the overall calculated impact of a CE metric defined as summing across all life cycle stages including Module D1 [13].
  - → Avoiding landfill by reducing materials brought to site that may subsequently end up being sent to landfill will reduce the overall mass M_i and Material Intensity of a project (see 1a above). Reducing M_i and Material Intensity is aligned with reducing the quantity of waste to landfill from site.
  - → Environmental impacts of waste to landfill during product manufacturing processes are reflected in product EPD. F_i derived from EPD information, is aligned with reducing waste to landfill. The environmental impact of waste from site to landfill is not available from objective data sources such as EPD and is therefore proposed not be part of the CE Outcome Metric. (Note that there are no existing CE process metrics pertaining to waste that take an accurate account of the environmental impact of waste to landfill and waste incinerated for energy.)

Second, looking at minimising waste post-completion:

- → The same considerations as in the previous point apply to the life-cycle stages post-completion. Although, as the reuse (or not) of building components at end of life is uncertain and subjective, impacts of end-of-life outcomes should not be included in the metric for setting limits and evaluating and rewarding performance (the CE Outcome Metric (Upfront)).

Appendix D: Review against Client CE Outcome Criteria

Client CE outcome criterion	Description
1. Objective, transparent and robust	Clients require the metric to assess, track progress and reward performance to targets, enforce limits, and hold key staff, consultants, and contractors (and therefore projects) accountable. In other words, it must lend itself to be written into project briefs and staff compensation agreements. Ultimately, this could lead to legislation of reporting and limits. To do so the metric must be objective, stand up to scrutiny, and be difficult to game. Such qualities would promote industry benchmarking efforts, with such clear consensus further underscoring its objectivity.
2. Universal and scalable	The metric should apply to all building typologies at any stage of the building life cycle. It should be easily aggregated across building elements, projects, and companies.
3. Simple and understandable	The metric must be easy to understand by experts and non-experts alike. It must be easy to communicate thus also promoting greater appreciation of the benefits of circular material use. The metric should advertise its underlying objective or purpose. A straightforward metric may be beneficial in educating e.g. insurers or shareholders in discussions about new materials and/or manufacturing processes.
4. Embedded in existing processes	The metric needs to 'fit in' alongside already commonly used management metrics. The data to populate the metric must be readily available, preferably already used by other management metrics so that it is familiar to management.
5. Able to evolve	The metric must be able to exist in a simplified form (e.g. low granularity of inputs) to promote a wide take-up and allow users to generate quick-wins. It should be future-proofed such as be sufficiently open-ended to incorporate future development, such as more detailed calculations, newly measurable ecosystem impacts, or future development of objective methodologies for measuring designing for disassembly.
6. Able to demonstrate a clear relationship with embodied carbon	Embodied carbon measures the climate impact of construction, and its recent uptake by industry has been rapid. Embodied carbon is a good proxy for the circularity of a project – the more circular, the lower the embodied carbon. The CE Outcome Metric would sit alongside embodied carbon as a key project metric and as such needs to demonstrate an ability to indicate additional circular economy benefits not already reflected in embodied carbon.
7. Good for clients and society	The metric needs to extend beyond the more familiar technical concepts (such as cost, programme, quality, carbon) and incorporate wider factors impacting the environment and socioeconomic factors.

Table 10 - Seven criteria for a single usable and effective CE metric which clients can use to set CE briefs on projects, developed in the Hackathon

A discussion of how the CE Outcome Metric meets the Client CE Outcome Metric Criteria is given in Table 11 below.

CE Metric Criterion	Evaluation
1. Objective, transparent and robust	The CE Outcome Metric (Upfront) in particular is composed largely of measurable/ objective variables, with information drawn from the project bill of quantities, building element EPD (or industry-agreed proxy factors), and nationally determined impact cost conversion factors following a process of transparency and public scrutiny and feedback. The CE Outcome Metric (Whole Life) is more subjective due to the assumptions needed to project CE outcomes into the future.
2. Universal and scalable	Prior to dividing by area, the CE Outcome Metric (Whole Life) sums across all building elements LCA stages* and environmental impact categories and is a £ monetary amount inherently summable within and across projects, companies, cities, regions, and countries. (* The CE Outcome Metric (Upfront) measures only upfront impacts to avoid subjectivity.)
3. Simple and understandable	The metric embodies the concept of summing up the total cost of mitigating the externalities resulting from the project (upfront and whole life). The more circular a project, the lower its environmental impact, the lower the calculated metric. Many of the environmental impact categories also represent the amount of pollution generated by the project; recent thinking has it that the average person is more likely to see pollution as a problem (and demand action on it) as it is more visible than CO_2 emissions.
4. Embedded in existing processes	All clients assess a project on the cost outlay (capital cost) and, some are starting to consider future projected expenditure (future lifetime cost). More forward-thinking clients report upfront and whole life embodied carbon measured in $kgCO_2e$ which can be converted to a costed GWP externality using carbon prices (inflated to more reflect the true externality cost). The CE Outcome Metric extends whole life and upfront embodied carbon to report the cost of all environmental externalities, sticking with a language and framework already existing around embodied carbon which clients are familiar. Consequently, it dovetails into embodied carbon/ WLC calculations already widely underpinned by a wide range of publications, guidance, and standards such as the RICS Professional Standard on Whole life carbon assessment for the built environment (September 2023), the Net Zero Carbon Building Standard, and Part Z [1]. This can accelerate its understanding, acceptance and use.
5. Able to evolve	Generic Environmental Impact Factors can be used initially, with greater resolution and further factors added over time.
6. Able to demonstrate a clear relationship with embodied carbon	As the impact of embodied carbon represented by the GWP is likely to be significant, the metric should be calculated three times: once with all environmental impact categories, once with only GWP, and once without GWP, so that it can be reported separately to highlight its impact. See worked example in Section 4.0.
7. Good for clients and society	The metric reflects both material scarcity and environmental impact and incorporates all EN-15804 measurable environmental impact categories. The proposed metric purposely excludes the important but difficult-to-quantify indicators such as social value and biodiversity loss. Future development could look at how to incorporate these. For now, the urgency of addressing the Earth's climate and ecosystem breakdown requires a consensus outcomes metric that can be fast-tracked into client briefs and legislation.

Table 11 - A discussion of how the CE Outcome Metric meets the Client CE Outcome Criteria

Appendix E: Environmental Impact Category weighting factors used in the Dutch MPG calculation

The Dutch MPG framework which underpins the mandated reporting of the whole life environmental impact of projects has been in force since 2013 [3].

Note that unlike MPG, the CE Outcome Metric does not standardise by projected service life for each component. It also recognises that limits can only reliably set on upfront impacts.

Table 12 below sets out the environmental impact categories and weighting factors used in MPG, which should be a starting point for the weighting factors in the CE Outcome Metric.

The MPG methodology deals with the problem of combining a large array of different units by using a cost multiplier (the Impact Weighting Factor in the table) – reflecting the cost of mitigating the impact on scarce resources and the environment – to convert the impact to Euro. Each life cycle module will have a Circularity Factor denominated in Euro. The carbon price in Set 1 of €0.05/kg or €50/tonne is considerably lower than currently valued by markets. Weighting factors need to be regularly reviewed – both their absolute and relative values – although this needs to be done in conjunction with a review of the levels of limits and thresholds.

	Unit		Impact Weighting Factor (€/unit equivalent)	
Impact category	Set 1	Set 2	Set 1 [14] (existing)	Set 2 [15] (proposed)
"Set 1": taken from EN 15804:2012+A1:2013				
Abiotic resource depletion (non fossil fuels) ADP	kg Sb-eq	kg Sb-eq	€0.16	€0.30
Abiotic resource depletion (fossil fuels) ADP	kg Sb-eq	MJ	€0.16	€0.00033
Global warming 100y GWP	kg CO_2-eq	kg CO_2-eq	€0.05	€0.07/€0.116
Stratospheric ozone depletion ODP	kg CFC-11-eq	kg CFC-11-eq	€30.00	€32.00
Photochemical ozone formation POCP	kg C_2H_4	kg NMVOC-eq	€2.00	€1.22
Acidification potential of soil and water AP	kg SO_2-eq	mol H+-eq	€4.00	€0.39
Eutrophication potential EP	kg PO_4-eq	see below	€9.00	see below
"Set 1": additional impact categories				
Human toxicity HTP	kg 1,4 DB-eq	see below	€0.09	see below
Freshwater ecotoxicity FAETP	kg 1,4 DB-eq	CTUe	€0.03	€0.00013
Marine water ecotoxicity MAETP	kg 1,4 DB-eq	-	€0.0001	-
Terrestrial ecotoxicity TETP	kg 1,4 DB-eq	-	€0.06	-
"Set 2" additional impact categories, based on EN 15804:2012+A2:2019				
Eutrophication aquatic freshwater	-	kg P-eq	-	€1.96
Eutrophication aquatic marine	-	kg N-eq	-	€3.28
Eutrophication terrestrial	-	mol N-eq	-	€0.36
Water (user) deprivation potential WDP	-	m^3 water eq	-	€0.00506
Potential incidence of disease due to particle matter (PM) emissions	-	kg disease incidence	-	€575,838.00
Potential human exposure efficiency relative to U235 (IRP)	-	kBq U235-eq	-	€0.049
Human toxicity, cancer effects (HTP-c)	-	CTUh	-	€1,096,368.00
Human toxicity, non-cancer effects (HTP-nc)	-	CTUh	-	€147,588.00

Table 12 - Environmental impact categories and weighting factors used in the Dutch MPG calculation

Appendix F: Frequently Asked Questions

Will the CE Outcome Metric have industry consensus?

The starting point for the CE Outcome Metric is the Hackathon Formula (Equation 3). This was developed through consensus by over 50 circular economy experts from the UK construction sector in a Hackathon co-organised by LETI, CIRCuIT and UCL in January 2023 (See Appendix A). However, it cannot be assumed that the proposed CE Outcome Metric in this Opinion Piece automatically also has the consensus of the original Hackathon participants.

Doesn't the impact of Embodied Carbon overshadow all other environmental impacts set out in EN 15804 and therefore skew the CE Outcome Metric towards GWP?

The impact of embodied carbon, represented by GWP (Global Warming Potential), is likely to be significant (see worked example in Section 4.0). The CE Outcome Metric should therefore be calculated three times: once with all environmental impact indicators, once with only GWP, and once without GWP.

What about hard to quantify impact factors?

For the time being, the CE Outcome Metric purposely excludes (1) difficult-to-quantify factors such as social value, biodiversity net gain, and (2) subjective factors whose impact may or may not be felt at some point in the future, such as adaptability or ease of design for disassembly scores. The urgency of addressing the Earth's climate and ecosystem breakdown requires a consensus metric based on objectively measurable impacts that can be fast-tracked into client briefs and legislation.

How does the CE Outcome Metric show the benefit of reuse?

It does so in the same way embodied carbon shows the benefit of reuse. The benefit of reuse shows up in the embodied carbon calculation through a reduction of upfront (Stage A), and post-completion embodied carbon (Stages B, C and D1) and will show up in the CE Outcome Metric as a reduction in total cost of the environmental impact factors via the same mechanisms. This is discussed in more detail in Appendix C.

The CE Outcome Metric incorporates the upfront and estimated future environmental impact of the project (whole life Environmental Externalities), which reflects reasonably anticipated reuse as a reduction in future environmental impacts (Stage B), and a reduction in end-of-life environmental impacts (Stage C and an increased contribution from Module D1 in reducing projected end of life environmental impacts).

How is waste reduction reflected in the CE Outcome Metric?

Waste reduction does not show up explicitly as a separate quantity, rather, it serves to reduce the overall value of the CE Outcome Metric. The overall quantities used to calculate the CE Outcome Metric (and embodied carbon for that matter) should reflect the environmental impact of the total amount of materials/products transported to site, and the environmental impact of unused materials disposed of. The environmental impact of waste to landfill is not incorporated in the CE Outcome Metric. This is discussed in more detail in Appendix C.

How is the CE Outcome Metric any better than the existing CE metrics for client briefing?

The CE Outcome Metric meets the requirements for client briefing and reflecting CE outcomes (Appendix D). It takes into account all environmental impacts in EN-15804, and the CE Outcome Metric (Upfront) is an objective measure (Figure 2). Appendix B sets out the most commonly used CE metrics and compares these with the CE Outcome Metric.

How will the CE Outcome Metric (Upfront) benchmarks and limits be developed?

Benchmarking allows institutions like LETI and RIBA to suggest limits for clients to use in briefing. Additional reporting fields can be added in Built Environment Carbon Database (BECD) returns; rules can be added to the Net Zero Carbon Building Standard (NZCBS). Benchmarks could also be derived from many years of collected MPG data in The Netherlands.

Isn't embodied carbon a good enough CE metric?

Embodied carbon is an excellent CE metric in that it shows the impact on GWP of 'upfront' circular design choices such as greater reuse, and reducing virgin resources, and 'whole life' choices such as more durable elements, designing in layers and designing for disassembly (Table 7 in Appendix A). The extent of the impact of circular materials use in a design can be shown by comparing the embodied carbon of the design with a version of the design without the circularity features. The problem with full reliance on embodied carbon as a CE metric is that it does not reflect all the other environmental impact externalities in the CE Outcome Metric. The overlap between CE and embodied carbon is considered in detail in the LETI Opinion Piece "Circular economy & carbon in construction" [16].

The CE Outcome Metric seems a lot of work to calculate. Is there a simplified version?

Calculating the CE Outcome Metric involves mostly the same procedures followed when calculating embodied carbon except that there are more environmental impact indicators to feed into the calculations; these are available in EPD alongside the GWP figures used in the embodied carbon calculations. Further development should focus on short-cuts and simplifications. An early proof-of-concept roll-out of the CE Outcome Metric might limit the environmental impact indicators to a smaller subset of impact factors, and main building elements, to expedite the process.

Using building area (usually GIA) to standardise the metric (via Material Intensity) does not work for infrastructure projects. Should total mass of materials not be used?

For most buildings, GIA is the best denominator to allow comparisons between projects and with benchmarks, whether it be for occupancy, cost, energy consumption, or upfront or embodied carbon. This is done for simplicity, ease of understanding and robustness. However, GIA is not applicable for projects with a large infrastructure component; the RICS Professional Standard on Whole life carbon assessment for the built environment (September 2023) section 3.2.7 outlines alternative units of measurement, for example for infrastructure (which is to standardise by length of roads or tracks, or station capacity) [17].

Why not just use the much simpler ratios such as "% reused" or "% reusable" for client briefing on projects?

This question often comes up. These ratios are good design tools, as they are intuitive indicators of minimising resource use and environmental impact.

Some metrics (such as percentages) are unitless which precludes scaling by simple aggregation across materials in a project, and across projects. Typically, mass is used to weight the numerator and denominator, but this leads to distortions as a material's mass alone is not a consistent or reliable indicator of environmental impact. To aggregate such unitless metrics, the variables to be used for weighting (e.g., mass, or the environmental impact itself which is part of the CE Outcome Metric) need to be reported in parallel to allow aggregation.

In line with this, when aggregating the reuse percentages for materials and products these should be appropriately weighted by the overall impact of their reuse. This Opinion Piece asserts that EPD (or estimates where EPD are not available) contain the most accurate objective information for this purpose.

This means that to create a meaningful aggregated "% reused" or "% reusable" metric, the same information as required for the CE Outcome Metrics is needed. As discussed in Appendix B, it is reasonable that materials with a greater environmental impact by mass have a greater F_i (as an indicator of virgin resource use) per unit of mass and receive a greater absolute reduction in F_i per unit of mass from reuse. For example, the mass-weighted impact of reusing aggregate (say, in concrete) should be much smaller than the mass-weighted impact of reusing steel or aluminium. Environmental impact per unit of mass seems to be a reasonable weighting additional to mass.

Unitless metrics don't indicate absolute impact and therefore cannot be incorporated into entity or national budgets (as is, e.g., currently done with GWP for NDCs).

The CE Outcome Metric is not a metric indicating % reuse. Rather, when multiplied by the building's floor area (GIA), it is an absolute magnitude metric and can therefore be used to evaluate the environmental impact of the smallest component of a project, as well as be aggregated across components, projects, companies, cities, and regions, to a national level, to derive the total cost of environmental externalities of the built environment sector.

This calculated cost of environmental externalities, or net 'environmental impact' is a good proxy for circularity. The greater the reuse and lower the waste, the lower the net environmental impact. The methodology for the CE Outcome Metric could be applied at a national level, enabling governments to set targets for materials circularity outcome through Nationally Determined Contributions (NDC) for net environmental externalities, just as they currently do for carbon emissions.

The CE Outcome Metric is a £ cost metric. This is subject to price inflation – is this not a problem?

Cost inflation causes the upfront project cost per square metre to increase over time, with target project budgets responding accordingly. Weighting factors need to be regularly reviewed – both their absolute and relative values – although this needs to be done in close coordination with the levels of limits and thresholds.

The CE Outcome Metric puts a £ price on environmental impacts. Won't clients be tempted to just offset rather than minimise the impacts?

The use of the CE Outcome Metric, which puts a £ price on environmental impacts, may well encourage offsetting of the impacts rather than amending the design to reduce them. Such practice should be scrutinised to the extent that carbon offsetting currently is. The act of transferring responsibility for mitigating impacts to others beyond the project boundaries, and the actual offsetting schemes available, can – and do often – lead to unintended negative consequences. This is a topic beyond the scope of the Opinion Piece. An excellent source of information on offsetting is the Oxford Principles for Net Zero Aligned Carbon Offsetting [18].

What if an EPD is not available?

See also Section 5.0 (Next Steps for further development).

The environmental impact factors as reported in product EPD are proposed to be used in the circularity factors, F_i.

Broadly speaking, the greater the extent of reused materials in products, the less likely they are (yet) to have an EPD, and this could put immature supply chains at a disadvantage. Suitable workarounds will likely vary by case. For components taken directly from other buildings without any processing the only new environmental impacts are from dismantling, transporting, and reinstalling these items. For remanufactured products, the environmental impact will be greater than this, and for products containing a mix of virgin and reused materials and components, the impact will be yet greater. Standard tables of default environmental impact and adjustment factors can be developed to bridge the lack of EPD. A free publicly available database of default environmental impact factors for different levels of reuse in products – like the ICE database for carbon (GWP) [4] – would address this potential lack of EPD. The Dutch Environmental Database [19] contains default factors to use in the mandatory MPG environmental performance calculation where individual product or product-type EPD are not available.

How does the CE Outcome Metric overcome the problem of different units of measurement of environmental impact indicators represented in the Circularity Factors F_i?

Appendix E sets out the set of environmental impact indicators (given in EPD) that are currently part of the Dutch MPG calculation mentioned above. It is suggested that all of these are used in the calculation of the CE Outcome Metric. Most are expressed in different units which means they cannot be aggregated as-is. MPG solves this by setting out weighting factors, each reflecting the cost (in €) of mitigating one a unit of each environmental impact indicator. The current MPG weighting factors are set by the Dutch government. These weighting factors are proxies for the cost of the environmental externalities of the production of a product [20]. Once converted to a cost of environmental externalities (in €, or £) the environmental impact indicators can be aggregated across all products used in the project.

The Circularity Factors (F_i in the Hackathon Formula, Equation 3) for each material are thus defined as the sum of all EPD environmental impact category values, multiplied by the UK-specific externalities cost weighting factors for each environmental impact category.

Aren't the environmental impact cost weighting factors subjective?

The environmental impact cost weighting factors are not measured but estimated using assumptions. This makes their calculation a subjective process; it is difficult to estimate a cost of reversing the different environmental impacts, or externalities. In particular, the relative values of the weighting factors are important to get right [21]. If the calculations are subject to public expert scrutiny and updated regularly to reflect the best available information, the weighting factors should represent the best national estimate of the cost of externalities. This reduces the negative impact of underlying subjectivity. Furthermore, the weighting factors apply across all projects nationally, and are therefore objective to the extent that they are fixed and the same in all calculations.

EPD don't normally provide information on modules B1-B5. How should these be evaluated in the formula for the CE Outcome Metric (Whole Life)?

EPD can include values for LCA Modules B1-B5, but they often do not, due to the uncertainty associated with what happens to building elements during the use phase. Whether these modules are included depends on the product type, the purpose of the EPD, and the availability of reliable data.

The information for modules B1-B5 should be calculated in the same way that it is done for whole life carbon calculations, following the methodology set out in the RICS Professional Standard on Whole life carbon assessment for the built environment, September 2023.

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Any errors and omissions are the responsibility of the lead author.

Notes and references

[1] See https://part-z.uk/.

[2] All environmental impact categories defined in EN-15978 and set out in product EPD. See also Section 5.0.

[3] MPG stands for "Milieu Prestatie Gebouwen", which translates to "Environmental Performance [of] Buildings". Reporting of this metric is mandatory for all building projects, and there are mandatory limits. See https://milieudatabase.nl/en/environmental-performance/environmental-performance-calculation/ and https://milieudatabase.nl/en/faq/. (Accessed April 2024).

[4] See the ICE (Inventory of Carbon and Energy) database by Circular Ecology at https://circularecology.com/embodied-carbon-footprint-database.html (Accessed August 2024).

[5] In the UK some have already made a stab at such adjustment factors. Net Positive Solutions has developed the Materials Value Retention hierarchy which proposes a basic set of six material-agnostic adjustment factors indicating the type of material reuse. See https://www.netpositivesolutions.co.uk/our-approach-1 (Accessed August 2024). EMR Group is currently developing a Circular Building Assessment too which assesses the impact of retention, reuse and recycling based on industry accepted GWP figures.

[6] "Circular economy guidance for construction clients: How to practically apply circular economy principles at the project brief stage", UKGBC, April 2019, available at https://ukgbc.org/resources/circular-economy-guidance-for-construction-clients-how-to-practically-apply-circular-economy-principles-at-the-project-brief-stage/ (Accessed August 2024).

[7] This column sets out LETI's summary interpretation of the EU Levels. Taken from https://susproc.jrc.ec.europa.eu/product-bureau/product-groups/412/documents (Accessed August 2024).

[8] See https://ukgbc.org/wp-content/uploads/2023/03/Circular-Economy-Metrics-Paper.pdf (Accessed August 2024).

[9] See "Het Nieuwe Normaal" (Dutch text) at https://www.cirkelstad.nl/het-nieuwe-normaal/ (Accessed August 2024)

[10] See LETI's Embodied Carbon Primer (2020) at https://www.leti.uk/ecp (Accessed August 2024).

[11] Available at https://www.london.gov.uk/programmes-strategies/planning/implementing-london-plan/london-plan-guidance/circular-economy-statement-guidance (Accessed August 2024).

[12] These three criteria are distilled from the multitudes of varying CE definitions. The European Parliament defines the purpose of CE as (1) protecting the environment (including waste generation) and (2) reducing raw material dependence (from https://www.europarl.europa.eu/news/en/headlines/economy/20151201STO05603/circular-economy-definition-importance-and-benefits, accessed August 2024). The Ellen McArthur Foundation defines the three principles as: "eliminate waste and pollution, circulate products and materials (at their highest value) and regenerate nature".

[13] Module D1 must be reported separately under EN-15804 LCA rules. Whether this restriction can be dropped for the CE Outcome Metric needs to be reviewed.

[14] The weighting factors for Set 1 are given in https://milieudatabase.nl/en/environmental-data-lca/information-for-life-cycle-assessment-lca-practitioners/environmental-impact-categories/ (Accessed August 2024). The source of these weighting factors is the document "Toxiciteit heeft z'n prijs, Schaduwprijzen voor (eco-)toxiciteit en uitputting van abiotische grondstoffen binnen DuboCalc" by drs. A.K. van Harmelen et al, 2004.

[15] The proposed weighting factors for Set 2 by the Dutch organisation Gideon in February 2024 are given in https://www.gideonstribe.nl/verhalen/het-voorstel-van-gideon (Accessed August 2024).

[16] See https://www.leti.uk/opinionpieces (Accessed August 2024).

[17] Appropriate units of normalisation for all project types are set out in the RICS Professional Standard on Whole life carbon assessment for the built environment (September 2023), section 6.2.3 "Normalisation units".

[18] See https://www.smithschool.ox.ac.uk/research/oxford-offsetting-principles (Accessed August 2024).

[19] See https://milieudatabase.nl/en/database/dutch-environmental-database/ (Accessed August 2024).

[20] At the time of writing, the GWP mitigation cost in the MPG framework has been set at €0.05/kg or €50/tonne, which is considerably lower than currently valued by markets. Weighting factors need to be regularly reviewed – both their absolute and relative values – although this needs to be done in close coordination with the levels of limits and thresholds.

[21] A starting point for the environmental impact category weighting factors could be the ones used in the Dutch MPG framework, set out in Appendix E.